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IMPROVING DIAGNOSTICS CAPABILITIES THROUGH ENHANCED MAINTENANCE DATA COLLECTION

Robert M. Rolfe, *Task Leader*
Herbert R. Brown

December 1990

Prepared for

Weapons Support Improvement Group (WSIG)
Office of the Assistant Secretary of Defense for
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The study reported in this paper examined primary, large scale DoD maintenance data collection systems to determine if they could or should be modified to enhance the use of information in order to improve diagnostics. The maintenance data collection systems in place, or being implemented, have principally automated previous manual reporting functions. The study concludes that these reporting functions are not intended for improving diagnostics, and furthermore, these systems rarely provide any direct benefit to the maintenance technician. This study also reviews the scope and capabilities of the DoD maintenance data collection systems, compares these capabilities with those found in the commercial sector during an earlier Joint DoD /Industry Study, and recommends near and long term actions to enhance DoD's capabilities to diagnose and troubleshoot military equipment.

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PREFACE

IDA Paper P-2423, *Improving Diagnostics Capabilities Through Enhanced Maintenance Data Collection,* was prepared for the Weapons Support Improvement Group (WSIG), Office of the Assistant Secretary of Defense for Production and Logistics (OASD(P&L)) in response to IDA Task Order T-B5-490 under MDA 903-89C-0003. The study reported here was initiated as a direct result of the observations and recommendations from the *Joint DoD/Industry Study on Opportunities in Integrated Diagnostics* [Brown 1990].

This paper reviews the scope and capabilities of the DoD maintenance data collection (MDC) systems, compares these capabilities with those found in the commercial sector during the Joint DoD/Industry Study, and recommends near and long term actions to enhance DoD's capabilities to diagnose and troubleshoot military equipment.

The paper was reviewed by the members of the following CSED Peer Review: Richard Ivanetich, Richard Wexelblat, Terry Mayfield, Robert Winner, James Pennell, David Dierolf, and Karen Richter. We also express our appreciation to Katydean Price and Sylvia Reynolds for their editorial advice and assistance, and to Betty Pinna and Janice Hirst for their word processing and graphics support. Finally, we thank Chris Fisher and Marty Meth of OASD(P&L) WSIG for their guidance and support.

EXECUTIVE SUMMARY

Many studies have reported that it is hard to quickly and accurately diagnose military equipment failures. Field maintenance accuracy today relies on highly specialized skills, large complex automatic test equipment, on-board built-in tests (that are often inadequate), and outdated technical information. The results are that significant DoD resources are tied up in unnecessary maintenance actions and parts removals, high manpower levels, and extensive technical training. Commercial companies reviewed in an earlier IDA study, the *Joint DoD/Industry Study on Opportunities in Integrated Diagnostics* [Brown 1990], were found to purposefully collect and apply diagnostic related maintenance information to greatly enhance diagnostic performance and cost effectiveness for their products.

The study reported in this paper examined primary, large scale DoD maintenance data collection (MDC) systems to determine if they could or should be modified to enhance the use of information in order to improve diagnostics. We found that the MDC systems in place, or now being implemented, have principally automated previous manual functions. While we observed that the products of these MDC systems are not intended for diagnostic functions, the net result is that these enhancements have not improved DoD diagnostic capabilities. Furthermore, these systems rarely provide any direct benefit to the maintenance technician.

We believe that very significant diagnostic improvements are practical if further steps are taken to integrate the processes of maintenance, data collection, analysis, and information feedback.

CURRENT SITUATION

Today's Service MDC systems are designed to collect information for maintenance management activities and to provide hardware usage information for the supply systems. Over a ten year period more than a billion dollars will have been spent for DoD MDC systems improvements to change the manual, paper based systems to automated data processing (ADP) systems. The principal result of this effort is the interconnection of existing MDC and logistics data bases.

These systems carry over many of the problems of the manual systems they replace. The normal benefits of automation are not being fully realized because of the continued need for manpower-intensive data input methods and the limitations of the hardware and software hosting the MDC systems. Rarely is the MDC information used to support or improve diagnostics; in fact, we found no organizations that acknowledge responsibility for the purposeful use of MDC data to improve diagnostics as a primary mission.

In contrast, maintenance diagnostic capabilities of the commercial companies investigated in the *Joint DoD/Industry Study on Opportunities in Integrated Diagnostics* were found to specifically and effectively use MDC data to enhance diagnostics capabilities. The commercial MDC systems transparently acquire maintenance data, analyze it promptly, and rapidly disseminate updated diagnostics information to the maintainer. Further, commercial companies commonly assign the responsibility for all aspects of diagnostics, including management of MDC systems to a single organization.

CONCLUSIONS

The Service approaches to providing and managing diagnostic capabilities are fractionated and this problem is particularly evident in MDC implementation. Improvements to diagnostics capabilities will require more than just changes in mechanics or scope of MDC systems. Fundamental changes in maintenance capability development and process management will be needed. Because of the substantial investments already made in fielding current "modernized" MDC systems, and because many of the MDC information products are justified and targeted for needed maintenance management and supply support functions, a focused study is needed before any major changes are undertaken. The study should look at both near and long term opportunities to effectively integrate MDC capabilities with diagnostics improvement processes that will produce substantial increases in maintenance efficiency.

RECOMMENDED ACTIONS

In the near term, the following actions are recommended to establish an environment for diagnostic improvement and to improve the efficiency and effectiveness of existing MDC capabilities:

a. Assign diagnostics and maintenance accountability to individuals presently working within each existing weapon system maintenance and engineering organization. This will establish a foundation, at the individual systems and subsystems organizations, where MDC information may be effectively analyzed and put to productive use for identifying diagnostic improvement needs.

b. Use available technology to automate point of entry data capture (e.g., F-18 engine and avionics data analysis, F-15 pilot debrief aids). These actions will improve data accuracy needed to support analyses and enhance the data integrity for existing MDC supported functions.

c. Provide automated links between MDC and new automatic test equipment (ATE) systems. These actions will help to reduce data collection work loads and data entry

errors. Furthermore, they will provide essential links for future data analyses across functional, maintenance, and product lines.

d. Encourage system contractors to propose new MDC capabilities or modifications to existing systems with the objective of increasing diagnostics capability. These actions will help stimulate creative ideas and promote a move away from the status quo to a more integrated approach.

For the long term, we recommend that the approach to management of maintenance diagnostics be reexamined. The suggested approach for DoD is outlined in our previous *Joint DoD/Industry Study on Opportunities in Integrated Diagnostics*. In this report we recommended that DoD develop a planning framework to facilitate the implementation of integrated diagnostic concepts. This planning framework should specifically address actions necessary to accelerate weapon system specific point of entry data capture for increasing data accuracy and completeness, to extend common MDC ATE systems for collecting and disseminating applicable diagnostic-related information, and to establish requirements and incentives for acquiring continuously improving designed-in MDC capabilities. We further suggest that while this examination is going on, the Services not start any further enhancements to MDC systems without reviewing the opportunities of more efficient integrated process approaches found in the commercial cases.

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1. INTRODUCTION

1.1 PURPOSE

The purpose of this study was to examine Department of Defense (DoD) maintenance data collection (MDC) systems to determine if they could and should be modified to improve diagnosing and troubleshooting military equipment. The study, requested by the Weapon Support Improvement Group (WSIG), Office of the Assistant Secretary of Defense for Production and Logistics (OASD(P&L)), examined selected DoD MDC systems. Study objectives were to assess how effectively DoD uses the collected data to improve diagnostic accuracy, to compare DoD practices with commercial MDC implementations that support integrated diagnostics, and to identify opportunities to improve DoD's weapons systems diagnostic capabilities through enhanced application of MDC systems.

1.2 BACKGROUND

A large fraction (estimated 25 to 30 percent) of a weapon system's lifecycle cost is spent on maintenance. Approximately 50 percent of this maintenance cost comes from the diagnostic processes of locating problems and identifying potential solutions. Maintenance effectiveness of field and depot activities is directly related to the speed, efficiency, and accuracy of the diagnostic process. The complexity of today's weapon systems has led to the establishment of field maintenance environments that require large logistics infrastructures. These infrastructures need specially trained personnel, dedicated complex test and support equipment, and volumes of technical manuals.

DoD maintenance communities believe that the existing diagnostic capabilities can and must be improved. False maintenance removal rates of between twenty and fifty percent for electronic equipment are common. However, these problems are not limited to the electronic equipment. For example, analyses of data for unscheduled maintenance of F-16A/B aircraft at eight Air Force bases in 1985 revealed the following percentages of "no-defect-found": flight

controls: 18%, turbofan power plant: 16%, fuel system: 23%, fire control: 49%, weapons delivery: 47%, and penetration aids and electronic counter measures: 19% [Petruschell 1987,p.30].

WSIG sponsored workshops in June and August 1989 to identify opportunities in integrated diagnostics. In this paper, the term integrated diagnostics is used to represent a process of improving diagnostic effectiveness and maintenance efficiency through the integration of pertinent elements such as testability, automatic and manual testing, training, maintenance aiding, and technical information. Case studies presented during these workshops highlighted successful commercial applications of integrated diagnostics.

> The case studies illustrated dramatic improvements in maintenance productivity and operating efficiency: (1) The General Motors Computerized Automotive Maintenance System demonstrated 33% improvement in maintenance shop productivity within 3 weeks of usage, (2) the AT&T 5ESS electronic switching system automated maintenance performance exceeds the system requirements of less than 3 minutes of down time per year, and (3) the General Electric Ground-based [aircraft] Engine Monitoring system on-wing (Lufthansa) maintenance performance analyses reduces maintenance overhaul budgets by 5% and reduces fuel consumption by an estimated 0.5%. [Brown 1990, p.vii.]

The key attributes found in these commercial examples, often contrasted with the perception of current DoD practices and guidelines [Brown 1990,pp.11-15]. The workshop participants observed that commercial systems with highly effective diagnostics capabilities typically employed effective MDC, centralized data analyses, and rapid feedback of critical information to both the design and maintenance communities. They went on to observe:

> Effective data feedback loops to the maintainers and designers are essential to successful integrated diagnostics implementation. However, the effectiveness and accuracy of field maintenance data collection for DoD systems are generally less capable than those illustrated in the case studies. DoD field units currently collect enormous amounts of data that are not being analyzed effectively [Brown 1990, p.89].

The data collected by the DoD MDC systems are incident to the maintenance and systems diagnostics processes, and not intended to specifically support systems diagnostics or improve diagnostics capabilities. Although the information is collected for a variety of reasons that are not directly tied to the diagnostics needs, there was strong consensus of the workshop participants that the available MDC information could be used to improve DoD diagnostics performance.

The study reported here was initiated as a direct result of the workshop observations. It is intended to focus on how DoD MDC data, as well as the related capabilities, may be used to improve diagnostics. Additional background information has been included in Appendix A, "Discussion of Terms," to provide a common framework for the reader of this paper.

2. APPROACH

2.1 SCOPE

At the onset of the study, we recognized that the DoD MDC systems have been established for purposes other than improving system diagnostics performance and accuracy. However, as observed by the participants in the Integrated Diagnostics Workshops, information collected by these MDC systems often finds its way back into various diagnostics element domains (training, documentation, reliability and availability data bases, etc.). As this information collects, actions that can influence diagnostics performance may be more easily analyzed and identified.

We also noted that the Services collect huge amounts of maintenance data by a variety of MDC systems. Therefore, in order to limit the scope, several DoD MDC systems, existing and under development, were identified for this study. The criteria for selection included (1) the systems selected must be representative of standard (or proposed future standard) MDC systems for a broad range of weapon systems, (2) the information collected or analyzed by the MDC systems must be representative of the type and range of data needed by the Service, and (3) the MDC systems should relate to operational weapon systems so that integrated diagnostics opportunities could be assessed.

2.2 SYSTEMS AND PROGRAMS EVALUATED

Table 1 presents a summary of the systems and programs evaluated during this study. Purpose and status summaries for each of these programs are presented by Service in Tables 2,3, and 4. Specific details regarding the individual systems and programs evaluated are presented in Appendix B, "Summary of Systems and Programs Evaluated."

Table 1. DoD MDC Related Systems/Programs Evaluated

AIR FORCE

- Core Automated Maintenance System (CAMS): Standard Air Force system for collecting maintenance data
- Comprehensive Engine Management System (CEMS): Turbine engine and related equipment tracking/management system
- Reliability and Maintainability Information System (REMIS): On-line Reliability and Maintainability data base
- Depot Maintenance Management Information System (DMMIS): Manufacturing Resources Planning (MRF) for depots
- Computerized Fault Reporting (CFR): F-15E pilot debriefing tool
- Reliability Asset Monitoring (RAM) & Tactical Missile Reporting System (TMRS): Reliability, maintainability, and availability (R,M&A) *tracking and management*

NAVY

- Naval Aviation Maintenance Program (NAMP): Overall Aviation Maintenance policy and procedures
- Aviation 3-M Data System: Paper-based approach for collecting maintenance data
- Naval Aviation Logistics Command Management Information System (NALCOMIS): Automate 3-M data collection
- Enhanced Comprehensive Asset Monitoring System (ECAMS): Engine and aircraft asset tracking and management system
- Consolidated Automated Support System (CASS): Update to Navy's current suite of automatic test equipment (ATE)
- Interactive Electronic Technical Manual (IETM): Program developing concepts and specifications for electronic prersentation
- Airborne Weapon Analyses and Reporting (AWAR): R,M&A tracking and management for missiles

ARMY

- Unit Level Logistics System (ULLS): Field unit level maintenance and supply management link
- Standard Army Maintenance System (SAMS): Direct and General Support maintenance and supply management link

Table 2. Air Force MDC Related Systems Reviewed

SYSTEM	PURPOSE	STATUS
CAMS	To automate and standardize the base-level maintenance data collection.	IOC was Feb 1985, and FOC is projected for Nov 1991. As of Dec 1989 CAMS was installed at 84 locations and by end of FY91 there are projected to be 113 systems. Next major software update to include the interface to the standard base level supply system.
REMIS	To interface with multiple MDC systems and provide for centralized storage and retrieval of data to support reliability and maintainability analyses at all product and support levels.	Very limited capability at time of this study. IOC of the EIMSURS subsystem (inventory and status reporting) was Dec 1989. IOC of the PPS which will collect and store the MDC information is projected for the end Sep 1990. IOC for the subsystem that will provide configuration status accounting is projected for the summer of 1992. Requirements for the final subsystem (which will track weapon system supply needs) was in the President's budget, and FOC projected for FY95.
DMMIS	To collect and control depot maintenance planning, management, and production control information. DMMIS will replace 29 existing maintenance management systems	Limited operating capability supports the first step (bill-of-materials, routing, and work-orders) and the second step (interface to supply). By late summer 1990, the third step will incorporate MRP II planning. The last step will include shop-floor and cost management capabilities at end of 1990. The program is developing a landing gear TRC, subsequent options are to implement an engine depot and to field DMMIS at other Air Logistics Centers. Options extend through to FOC in FY93.
CEMS	To support turbine engine management information needs (configuration management, serialized tracking, change tracking, and maintenance data).	IOC of CEMS I occurred in the early 1980's. At present all increments are in place; however, full implementation of CEMS IV for new engines and bases is still evolving. The full CEMS IV engine diagnostics and trending analyses capabilities have only been implemented on the engine for the A-10 (Note that the A-10 engine uses the Turbine Engine Monitoring System (TEMS) to collect the parametric data for CEMS IV.).
CFR	To replace the current A/C fault reporting manuals with an interactive rule based program and improve fault assessment during pilot/crew-chief debriefings.	The CFR was prototyped for the F-15E aircraft, and full scale development is continuing as part of the F-15E development/acquisition program. Future goals include transporting the CFR computer shell to host fault reporting capabilities for the F-15A-D aircraft and later the F-16 series aircraft. IOC is projected for FY93.
RAM & TMRS	To provide reliability, maintainability and availability tracking and management for tactical missiles.	The capability was developed as a result of the combined efforts of HQ TAC and LMC, and has been operational for several years. A new system that will include transparent data collection as well as other features is now in the planning stages.

Table 3. Navy MDC Related Systems Reviewed

SYSTEM	PURPOSE	STATUS
Aviation 3-M	To collect maintenance related data for intermediate and organization (I&O) level maintenance planning, production control, and resource tracking.	A well established paper based MDC approach that is implemented at all aviation related I&O-level maintenance facilities. Data collected on standard forms are entered on magnetic tape medium and summarized by various data service centers. The data on magnetic tape is forwarded to the Naval Maintenance Support Office.
NALCOMIS	To provide maintenance and supply managers with timely/accurate data for decision making, to reduce administrative burdens, and improve the data quality.	The first implementation of NALCOMIS is at the Intermediate Maintenance Activity (IMA) and is focusing on the interface to supply. It has been implemented at 6 out of a planned 88 IMAs. Current objectives are striving for completion of the I-level capability by FY95 with O-level implementation in FY97.
ECAMS	To provide on-board aircraft asset, primarily engine, monitoring and parameter recording capabilities.	Two versions of ECAMS are operational, one for the F-18 and the other for the F-14 aircraft. Early series of the F-18 use a tape transport magazine, while the later series of the F-18 and the F-14 use a data storage unit to collect and download information. The ECAMS capability on the F-14 has been available for about 6 months.There are approximately 110 ECAMS (PDP11) computers at field locations and the Navy is currently investigating options to field a PC compatible version.
CASS	To update and replace the Navy's standard suite of I-level maintenance facility automatic test equipment.	The CASS program is just completing its Technical Evaluation/Operational Evaluation at Patuxent River Naval Air Station. The Low Rate Initial Production decision is projected for August 1990. Option 1 of the contract will acquire 99 units with an approximate 16 months delivery time for the first units. Full rate production is planned for 1992 and there are three years of contract options.
IETM	To develop the requirements, standards, and specifications for future interactive electronic presentation devices.	This effort is part of a tri-Service research and development effort to define requirements for and develop specifications and standards that may be used in the future. Early targets for these new technical information delivery devices include the A-12, ATF and LH programs.
AWAR	To track and monitor the reliability, maintainability, availability and quality of deployed missile systems.	A well established paper based reporting system for missiles. The program is controlled under the Naval Airborne Weapons Maintenance Program. At present the Fleet Tactical Analyses Center is investigating options to transition to a PC-based data collection system that will permit transparent data collection by using bar code readers.

Table 4. Army MDC Related Systems Reviewed

SYSTEM	PURPOSE	STATUS
ULLS	To manage and request support for maintenance actions that are beyond the capability of the unit level. ULLS is replacing the old paper forms with floppy disks.	Milestone 3 (production decision) completed FY 90, and initial fielding of the ULLS capability on standard portable computers is in process.
SAMS	To automate the maintenance management processes at the direct and general support levels. SAMS is used to coordinate work loads, monitor availability, and coordinate repair parts utilization for maintenance.	Acquisition milestone 3 was approved in FY 86. The first fielding of SAMS was in Germany in 1987. At present, the world wide active Army requirements are essentially complete. The National Guard and Reserve requirements are approximately 50 percent complete. Full fielding anticipated in FY 92.

2.3 METHOD

Acknowledging that DoD MDC systems are not intended to improve diagnostics capabilities, we attempted to assess and characterize the application of DoD MDC systems to support comparable levels of diagnostics improvement found in the commercial case studies. The conclusions and recommendations presented in this study are based on the findings resulting from personal interviews, MDC program documentation, site visits, and the results of the earlier Integrated Diagnostics Workshop Study.

Discussions with the various MDC program offices, focused on the type and range of data collected, the intended purpose of this information, the identification of examples or initiatives where the data are intended for diagnostics related efforts, comparisons of DoD MDC system attributes with those identified during the Integrated Diagnostics Workshop, and opportunities to improve feedback and analyses capabilities through enhancement of MDC systems.

During visits with maintenance personnel, discussions focused on how the data are collected, what portions of the data collected are used at the local maintenance level, and how frequently the data are used to support diagnostic related needs. Discussions also addressed current and future technical information needs. This discussion topic was included due to the high degree of data correlation found in the commercial sector examples between technical manuals, the system configuration, the appropriate diagnostic procedures, and the pertinent maintenance information collected.

2.4 STRENGTHS AND WEAKNESSES OF APPROACH

Although the research is intended to apply to all DoD systems, this study tends to emphasize aviation maintenance applications. The vast number of MDC-related systems made it impractical to look at the full range of applications; and additionally, the primary DoD MDC systems available for study tended to be associated with this application area.

This study is a direct result of the following observations: (1) Commercial systems with highly effective diagnostics capabilities typically employ effective MDC that rapidly feeds back diagnostic improvement information to the design and maintenance communities, and (2) DoD MDC systems, although they collect huge amounts of information, are not directly tied to diagnostics improvement processes. It is natural to ask whether the commercial diagnostic improvements were due to the effective MDC systems or if the improvements might have been due in part to other factors such as increased management awareness. Although full consideration of this issue is beyond the scope of this study, we believe that concerns regarding this reasoning are

minimized by the methods used in this study. Specifically, the study focused on the opportunities to use the collected information to improve diagnostics capabilities on operational weapon systems, independent of whether effective MDC applications were the cause of diagnostics improvements for the commercial systems reviewed.

Exceptions to the general MDC system attributes and application trends identified in this study may be found throughout both the commercial sector and DoD. We believe that the *significance of observations in this study rests not with the identification of specific* weaknesses for any commercial or DoD MDC applications, but rather, with the identification of opportunities to enhance maintenance and diagnostics performance across a broad range of systems.

3. OBSERVATIONS

The following present the study observations. These observations illustrate many of the underlying causes of diagnostic accuracy and maintenance efficiency problems and help identify opportunities to improve diagnostic capabilities through effective feedback of MDC information. Since many of these observations apply equally across functional areas, they have been grouped under four convenient topics that provide a composite view of DoD maintenance and diagnostic environments: factors influencing diagnostic accuracy and maintenance efficiency, specific MDC system deficiencies, MDC system costs, and comparison of observed DoD practices with commercial MDC implementations. All interviews or discussions noted in the following sections were conducted as a part of this study unless a reference is provided at the end of the paragraph.

3.1 FACTORS INFLUENCING DIAGNOSTIC ACCURACY AND MAINTENANCE EFFICIENCY

A wide range of factors were observed to influence DoD's diagnostic accuracy and maintenance efficiency. The following list summarizes the observations presented in this section.

a. DoD lacks dedicated organizations and processes for improving diagnostics.

b. MDC systems are slow responding to maintenance technician needs.

c. The experience of the workforce is limited relative to the required maintenance tasks.

d. Technical manuals contain inaccurate diagnostic procedures.

e. Technical manuals are rarely followed precisely.

f. Information that should be stored in MDC systems is frequently false or missing.

g. MDC systems generally increase the maintenance technician work load.

h. Data entry processes are constant sources of error.

i. MDC data are incomplete and inaccurate relative to diagnostic improvement needs.

3.1.1 Deficiency Reporting

a. We found no Service organizations that acknowledged responsibility for the purposeful use of MDC data to improve diagnostic capabilities as a primary mission.

b. Maintenance personnel from the Army, Navy, and Air Force observed that the primary approaches used by the Services to identify and report weapon system deficiencies are slow, non-responsive, and not integrated with the MDC systems. They indicated that the various deficiency reporting (DR) mechanisms used by the Services are based on infrastructures that are fragmented across product and support levels, and depend on data from sources that are outside the DR span of control. They noted that rarely is MDC data used to support or improve diagnostic performance.

c. The Navy IETM study found that the Technical Publication Deficiency Reporting (TPDR) process is not responsive to corrective needs and that less than 50% of those interviewed ever receive confirmation of disposition for submitted reports. Another approximately 25% never submitted a TPDR; this high percentage is attributed to the low level of confidence in the reporting process [IETM 1990].

d. The Air Force has formal processes whereby maintenance technicians may report deficiencies for both the design (using Material Deficiency Reports or MDRs) and the technical manuals called Technical Orders (using AFTO Form 22). In both cases the technicians feel that a great deal of time elapses between submitting a report and receiving a response, and the quality of the response by the evaluator is generally quite low. Air Force personnel who are assigned the responsibility of answering these reports acknowledge that they do not have adequate resources to either review the reports or, more importantly, to initiate corrective actions. The problems associated with deficiency reporting for AF Technical Orders (TO) represent "an especially serious situation because TOs are inevitably immature when initially fielded and consequently need extensive field participation for their improvement [Gebman, 1988]."

3.1.2 MDC Systems Slow Responsiveness to Operational Maintenance Needs

a. Personnel interviewed stated that the Navy Data Storage Units (DSU) on board some of the aircraft are not read until the capacity of the unit is around 80% full (approximately 3 flights). This practice varies from squadron to squadron, and the use of the information appears to be driven by personalities more than by policy. However, the data from the DSUs are down-loaded more frequently if mission critical information is

needed by the mission planners or operations personnel.

b. Navy maintenance personnel experienced in aircraft carrier operations observed that current diagnostic-related MDC data are not available in time to support the normal turn-around times dictated by operational scenarios.

c. Air Force maintenance personnel indicated that it is common for an aircraft grounding problem to be diagnosed and fixed before the data is entered into the CAMS data base. This also was witnessed by the study team during site visits.

3.1.3 Limited Workforce Experience

a. Fifty percent of the personnel interviewed in a Navy IETM study had only 1 to 3 years in their current work center. An additional 34% had less than 1 year in the current work center [IETM 1990].

b. Fifty-seven percent of the personnel interviewed in a Navy IETM study had 1 to 3 years experience on their current weapon system. An additional 19% had less than 1 year on their current weapon system [IETM 1990].

c. Contractors for both the F-15 and F-16 radars found that debriefing of pilots is commonly handled by maintenance technicians who lack specialized knowledge about the radar systems. To compound the situation, these technicians often must debrief multiple sorties by several pilots at one time. "Because of the shortcomings of these debriefings, pilots fail to provide information necessary to identify faults and fault codes, and maintenance personnel often ignore the radar malfunction codes produced at the debriefing." In addition, the debriefers who are unfamiliar with the radar systems experience great difficulty using the fault code manual. "During the radar R&M program, debriefing personnel correctly assigned the proper fault code only 35% of the time [Gebman 1988]."

d. During a pilot debriefing, witnessed as a part of this study, the technician performing the debriefing was unable to locate the proper code in the aircraft Fault Reporting Manual. Furthermore, this individual had very limited maintenance and systems experience. Discussions with the Dispatcher (the individual who usually assigns the tasks to a specific shop based on the results of the debriefing process) indicated that he (the dispatcher) did not place much credibility in the fault codes coming from the pilot debriefing process and simply attempted to send the task to the appropriate shop for action.

3.1.4 Technical Instructions Not Followed and Contain Immature Diagnostics

a. The Navy IETM study found that due to operationally-related environmental constraints, the Navy technical manuals (including the check lists) are used less than 50% of the time in a step-by-step manner at either the intermediate or organizational (I or O) level of maintenance [IETM 1990].

b. Research under the IETM-related studies demonstrated an increased acceptance by maintenance personnel to use available technical information when the information was provided by electronic technical manuals. These studies also demonstrated substantial opportunities to improve diagnostics accuracy (see Section B.2.5, "IETM", for additional information).

c. During an Air Force R&M Study, maintenance technicians were seldom observed referring to technical manuals except when dealing with the most difficult faults, such as wiring problems [Gebman 1988].

d. Air Force Tactical Air Command (TAC) discovered that the F-15 trouble-shooting Technical Order was not being followed because the manuals were too complicated and many of the fault codes were inaccurate. Upon further study, TAC discovered approximately 350 voids in the fault tree documented by these manuals (see Section B.1.5, "CFR" for additional information).

3.1.5 Environmental and Operational Constraints

a. Maintenance personnel interviewed during this study indicated that *the physical use and step-by-step application* of fault isolation and detection information from the technical manuals and even check lists are often severely hampered by environmental conditions (bad weather, night time conditions, flight-deck maintenance environments, mud, etc.).

b. Rarely is it practical to bring all of the needed technical information to a problem site. A trace through the reference material for a moderately complex task on the F-18 aircraft revealed that 11 manuals and 33 work packages were required to perform the identified task from fault isolation through final checkout [IETM1990].

c. We observed that the DoD MDC systems are neither convenient for the technician nor compatible with the maintenance process. For example, the Air Force CAMS terminals, as currently implemented, are placed at locations separate from the

organizational maintenance work sites, thus making CAMS ineffective for immediate diagnostic analyses. During the visits maintenance personnel indicated that the lack of CAMS equipment at maintenance sites frequently forces the technician either to remember the maintenance data for future entry into CAMS or to generate paper documentation that must later be entered. Both of these situations affect the maintenance workload and are prone to human error.

3.1.6 MDC Information Integrity

a. During site visits, one maintenance technician cited a case where the CAMS information showed 4 sets of different serial numbers for a single LRU part number installed in a F-15 radar even though the aircraft radar will accept only one of these units.

b. A pilot debriefing session was witnessed where no maintenance actions were recorded in the MDC data (i.e., the aircraft was reported to have landed in a category 1 status). However, in fact, the aircraft had landed with a grounding condition (category 3) due to a radar problem. In this specific case a serialized unit was removed and replaced by maintenance prior to the pilot debriefing. Maintenance personnel observed that in order to keep an organization's quality/performance metrics high, the maintenance actions of this nature are frequently not reported. As a direct result of these events, the MDC data for that radar now had an invalid LRU serial number and the true "how malfunction" and "discrepancy" codes for the failed unit were suspect.

c. Both Air Force and Navy maintenance personnel cited examples where the technicians select convenient or easy to remember codes for many of the MDC data fields rather than looking up the precise code for the specific condition. The people interviewed attributed this problem to the proliferation of potential codes, the time consuming problem of looking up specific codes, and the level of training and experience of the work force.

d. Personnel from an Air Force avionics maintenance shop cited examples where they have entered the data and later learned that due to a subsequent CAMS down time or lock-up, the data was lost. However, since the data was entered in near real time (the way the system is intended to work), paper back up information had not been created. They commented that CAMS does have a system save-to-tape capability; however, it does not always prevent the loss of data.

3.1.7 Work Load Impact

a. We observed that the improvements offered by the MDC systems studied are principally those of automating paper based functions and providing interconnections between various existing logistics and MDC data bases. The Service MDC systems (both paper-based and automated) are designed to collect information for the management of maintenance activities and to provide parts/equipment usage information. In general, the workload of key punching information from paper-based maintenance activity summary forms was reduced by the new MDC systems. However, a new, additional, data entry workload was imposed on the skilled maintenance technician.

b. Air Force aircraft crew chiefs cited numerous examples where the CAMS data entry and forms checks took more time to complete than the actual maintenance action required to fix an aircraft. One crew chief cited a specific example where the maintenance actions on his aircraft (which had been in a cannibalized status for a period of time) took approximately one and a half days to return the aircraft to a flight worthy condition. However, the CAMS data input and job close out took three days.

c. Most of the crew chiefs interviewed felt that the data entry in CAMS represented a duplication of the required aircraft paper forms. Without exception, everyone acknowledged that the CAMS information lagged behind the data entry in the required paper forms, and that the various paper forms were the primary means of determining immediate update status. There was a perception that paper would always be the primary source of immediate status information due to the many potential problems that could influence the CAMS output (power outage, deployment, remote site operations, down time, etc.).

d. We observed that the DoD MDC systems lack common communications links that permit convenient data transfer between MDC related systems as well as transparent data collection from operational weapon systems. In general, we found that DoD uses manual communication links for entering data into the MDC systems. Even when the data are captured automatically, the information finds its way back into paper forms that must be later key punched into another MDC system.

3.1.8 Data Entry Concerns

a. The CAMS users felt that additional internal editing and processing could make the system more responsive to their needs. Examples they cited included more checking of

input fields to ensure data compatibility at the time of input, and more automatic data entry of common data on subsequent screens.

b. All of the CAMS users interviewed felt that there are too many different screens to remember. They also commented that the response time of some screens is excessively slow. Furthermore, in the menu mode (CAMS provides screen prompts), the responsiveness of the system is even worse.

c. CAMS data entry proficiency was identified as a significant concern in each of the maintenance areas visited. The users commented that this problem is compounded by the constant software updates. Limited training is available for CAMS and most of the personnel gain proficiency through on-the-job-training. Fortunately, this training is made manageable by the fact that each maintenance area needs to learn only a few of the CAMS screens. Approximately, one-quarter of the operators observed during the visit requested assistance for selecting the appropriate code, screen number, mode, or input data. A common practice in some of the maintenance areas was to designate an expert CAMS user as the individual responsible for entering data.

d. On two occasions during the site visit to a CAMS user, the study team witnessed maintenance personnel, who were entering data into CAMS, being reassigned to other maintenance tasks. Personnel interviewed indicated that this is a common problem. Data entry is assigned a lower priority than the maintenance actions. Maintenance personnel observed that since paper-forms have been filled out at the aircraft (thus meeting basic safety and operations concerns), there exists a general policy that the CAMS entry may be deferred until later.

3.1.9 Incomplete and Inaccurate MDC Data

a. Figure 1 summarizes the diagnostics-related information resulting from maintenance actions. It highlights critical information that is typically not reported in the DoD MDC systems, yet is essential for diagnostics process and design evolution. Without this information it is not practical to correlate the reported problems, the diagnostic procedures applied, the equipment configuration, and the corrective maintenance actions.

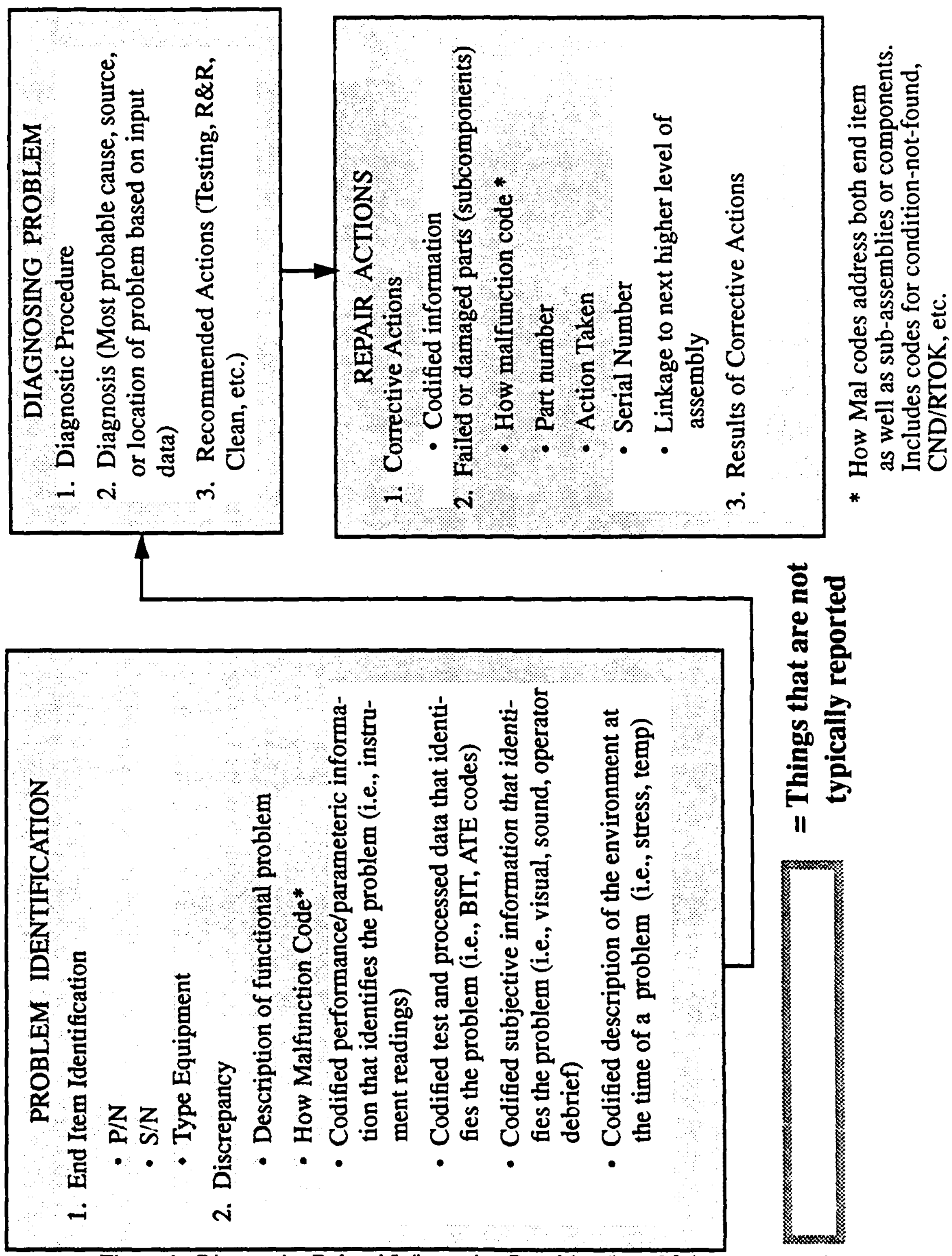

Figure 1. Diagnostics Related Information Resulting from Maintenance Actions

b. A recent Rand Corporation report noted that the following support weaknesses contribute to poor fault isolation performance: inadequate information about avionics equipment during flight, the lack of serial number tracking of avionics equipment, and inadequate integration of maintenance efforts and fault information across maintenance levels [Gebman 1989, p.32]. We observed that the contributing factors to each of these weaknesses would be reduced by instituting processes that collect the missing information highlighted in Figure 1.

c. There was general agreement among the personnel interviewed that the automated MDC system improved the accuracy of the collected information. However, they also identified persistent problems involving the integrity of the collected data that were not eliminated. Error sources most frequently cited included errors based on the technician remembering the proper codes, personnel selecting convenient codes which will always be accepted by the system, multiple serial number entries for the same part number, re-key punching data from paper, proficiency of personnel using the system, the long delays from the time the data was collected until the time that the data is entered into the system, incompatibility of the systems to accept the data in the same time sequence as it was acquired, lost data due to system crashes, frequent work-around-tasks that are not entered into the MDC data in order to inflate reported organizational metrics, and the unfriendly nature of some of the MDC systems.

3.2 SPECIFIC MDC SYSTEM DEFICIENCIES

The following sections summarize MDC system specific deficiencies observed by the authors during this study.

3.2.1 CASS and NALCOMIS Information Interface

CASS will incorporate several desirable features found in the commercial sector MDC systems: automated (transparent) data collection, paperless technical manuals resident in the system, and automated storage and retrieval of maintenance information within the CASS. It also will automatically produce the VIDS/MAF (paper) forms used in the Naval Aviation Maintenance Program (NAMP) for both maintenance production control and maintenance data collection.

However, the direct electronic link to NALCOMIS and other MDC type systems was eliminated due to budget and program constraints. At present, the information found on this VIDS/MAF form will have to be re-entered manually into NALCOMIS. Furthermore, the additional detailed diagnostic-related information which will be collected by CASS and will be essential for correlation of maintenance

processes, is not included on the VIDS/MAF form. Therefore a significant portion of the detailed MDC information will not be available for centralized diagnostic analyses.

3.2.2 CAMS Performance and Operational Inefficiencies

Although CAMS provided improvement in both MDC efficiency and data integrity over the past seven years, significant system performance and operational inefficiencies persist. The current CAMS problems are related to several very significant conditions: (1) the system is based on over ten year old technology, (2) the system is not hosted on its own dedicated computer, (3) the implementation concept is focused on automating a paper MDC concept as opposed to improving maintenance efficiency and (4) the system is not accessible at the on-equipment maintenance sites.

The system and operational problems involving the CAMS are summarized:

- Excessive system down time
- Too many screens and slow responsiveness of screens
- Work load impact and excessive time required for data entry
- Persistent training and proficiency-related problems
- Lags as well as duplicates the aircraft paper forms

As a consequence of these problems, CAMS provides very little support to the maintenance technician, and frequently represents an additional work load burden. In fact, very few of the CAMS benefits apply directly to the maintainer.

3.2.3 Turbine Engine Prognostic Capabilities (CEMS IV and ECAMS)

A significant number of Air Force and Navy turbine engines are compatible with the advanced monitoring capabilities; however, only a fraction of these engine types have been analyzed sufficiently to assure accurate maintenance prognostic capabilities. CEMS IV provides a very comprehensive capability to support engine diagnostics and to prognosticate trends that will require maintenance actions. The system will collect parametric engine performance data transparently (automatically, and without additional maintenance technician intervention) and couple this information with oil analysis program (OAP), component life expenditures, and other maintenance history data already collected. However, at present within the Air Force, only the technical data for the A-10 aircraft engine (TF-34) has been sufficiently analyzed to yield the full range of prognostic and diagnostic opportunities from the CEMS IV.

Currently, similar parametric information is being collected for the B-1, F-15,and F-16 engines, but the engine technicians are not able to use this diagnostics capability to its fullest extent since they are not always certain what the trend data they are collecting actually indicates.

The Navy ECAMS system automatically down loads engine and other aircraft parametric data via a data storage unit (DSU). As a result of situations similar to those identified for CEMS IV, ECAMS currently supports trend and event diagnostics only on the new upgrades to the F-14 aircraft engines (F-110). ECAMS does not provide the same capability for the F-18 aircraft engines (F-404).

The problem associated with the lack of analyzed information necessary to support the full range of prognostic opportunities is further exacerbated by the fact that there exists two distinctly different software implementation of ECAMS for the F-18 and F-14 aircraft. The Navy is investigating opportunities to develop a single ECAMS implementation.

3.2.4 Limited SAMS Codified Data.

Although, SAMS is providing a greater continuous flow of maintenance information for centralized analyses, the information collected is at too high a level of abstraction to support diagnostics improvement. Specific detailed codified information that addresses the reported problem, parametric operational data, the serial number of involved parts, and actions taken are all essential ingredients for the Army MDC system to effectively support diagnostics improvement.

3.3 MDC SYSTEM COSTS

The cost to develop and field the MDC system features reviewed in this study are in the order of several billion dollars. A rigorous assessment of these costs is beyond the scope of this study. Furthermore, it would be very difficult, and highly subjective, to separate the specific MDC related development costs from the cost of other functional capabilities in many of the systems studied.Therefore, the following cost information provided by the respective program offices provides only a top level review of the costs associated with selected MDC systems. It should also be noted that the various cost amounts address a range of then-year-dollars and represent a mix of development, acquisition, and operations and maintenance (O&M) resources.

We observed from the various MDC system program documentation that the justification and rationale for the individual programs focused on areas other than diagnostics accuracy improvement. We inferred from this that the synergistic processes used to improve diagnostic

performance, similar to those found in the commercial case studies during the Integrated Diagnostics Workshop [Brown 1990], are not funded goals of the following programs.

a. CAMS: Estimated development, acquisition, and O&M costs covering approximately 10 years through to full-operational-capability (FOC) projected for November 1991 -- $265 million.

b. NALCOMIS: Estimated life cycle costs that includes development, acquisition and support for 30 years -- $1.3 billion.

c. REMIS: Estimated development, acquisition and O&M costs covering approximately 10 years through FOC project for FY 95 -- $136 million.

d. DMMIS: Estimated development, acquisition and O&M costs covering approximately 6 years through FOC projected FY 93 -- $242 million.

e. CEMS: Estimated acquisition cost for the turbine engine monitoring system (TEMS) used to collect the parametric data from the A-10 aircraft engine for CEMS -- $94 million. The estimated development and acquisition costs for the CEMS data storage and retrieval capabilities -- $35 million.

3.4 COMPARISON OF OBSERVED DOD PRACTICES WITH COMMERCIAL MDC IMPLEMENTATIONS

The following compare the observed DoD maintenance and diagnostic practices with the commercial MDC implementations.

a. We observed that current DoD MDC systems may highlight diagnostic problems but do not pinpoint the diagnostic improvements needed. This dramatically contrasts with commercial case studies previously evaluated at the Integrated Diagnostics Workshop in which the commercial systems were found to specifically emphasize identification and resolution of diagnostic and equipment problems [Brown, 1990].

b. Based on the general information gathered during the study, the authors perceive that DoD tends to place higher priority on availability than costs. This trend was found to contrast with the commercial sector case studies, where costs were assigned higher priority. This led the authors to observe that DoD tended to automate the processes of MDC for the purpose of enhancing maintenance logistics and resource utilization, whereas, the commercial sector tended to automate diagnostics maintenance aids for the purpose of providing rapid improvement of diagnostic and product designs.

c. The ability to identify and isolate opportunities for improving diagnostic and maintenance efficiency within the DoD environment were found to be highly personality dependent. Rarely was an individual or organization observed to be responsible for specifically improving the accuracy and capability of the individual diagnostic elements. In contrast, the commercial cases reviewed specifically assigned the responsibility of diagnostic improvement to an organization.

d. Table 5 compares the commercial and DoD MDC implementation practices observed during this study.

e. Table 6 compares the general commercial and DoD MDC system application scopes observed during this study.

Table 5. Comparison of Commercial and DoD MDC Attributes

Attributes	Commercial	DoD
• MDC supports the correlation of maintenance activities across product and maintenance levels (1)	Yes	No
• The MDC information is useful for (and used by) the maintenance technician	Frequently	Rarely
• MDC system used automated or transparent data collection	Frequently	Rarely
• Data is input into the system close to the maintenance	Yes (since transparent)	Rarely
• MDC is closely tied to both the technical information and the system configuration	Yes	Rarely
• Configuration control of the relationship between the MDC and diagnostic processes	Yes	Rarely
• MDC system collects and stores parametric values	Frequently	Rarely
• MDC system collects and stores useful declaration of fault, problem, or malfunction information	Yes (generally very specific data)	No (generally at a very high level of abstraction)
• Central analysis facility for rapid feedback analysis and update of diagnostic information	Yes	No

(1) Correlating the maintenance process refers to the ability to thread from the reported problem, to the diagnosis, to the maintenance actions, and finally, to the results of the maintenance actions.

Table 6. Comparison of Commercial and DoD MDC System Scope

Capabilities	Air Force	Navy	Army	Commercial
• Maint. Scheduling	• Supports	• Supports	• Supports	• No
• Status Reporting	• Yes	• Yes	• Yes	• Sometimes
• Inventory Tracking	• Yes	• Yes	• Yes	• Sometimes
• Parts Life & Time Change Tracking	• Yes	• Yes	• Yes	• Yes
• Configuration Mgt.	• Reports & Tracks	• Reports & Tracks	• Reports & Tracks	• Reports & Interfaces with diagnostics
• Training Mgt.	• Yes	• No	• No	• No
• Personnel Mgt.	• Yes	• Yes	• No	• No
• Supply Interface	• No (Planned update to CAMS)	• Yes (NALCOMIS at I-Level)	• Yes	• Not Applicable
• Prognostic	• Limited (CEMS IV on TF-34 engine)	• Limited (ECAMS for F-110 engine)	• No	• Yes
• Diagnostic	• No	• No	• No	• Yes
• Electronic Display of Technical Information	• No	• No (However, will be on CASS for each test station)	• No	• Yes

(1) Includes both paper based and automated DoD MDC information.

4. CONCLUSIONS

4.1 DOD LACKS A FOCUSED PROCESS FOR IMPROVING DIAGNOSTICS

DoD's diagnostic capabilities are limited by the lack of a focused process for improving diagnostic performance. Slow diagnostic accuracy improvement is a systemic DoD problem. The maintenance and support processes, in contrast with the commercial cases studied, rarely use the MDC information to identify opportunities for diagnostic improvement. As a result, the maintenance and support processes used by weapon system managers tend to perpetuate the status quo rather than improve diagnostic capabilities. Many of the diagnostic inaccuracies that are present at the time a new system is fielded (or at the time a system modification is implemented) have a tendency to remain for the life of the system. Consequently, the cost avoidance opportunities that may be attributed to more accurate diagnostic and enhanced maintenance efficiency are lost

4.1.1 Diagnostic Process Systemic Problems

We conclude that the DoD diagnostic improvement process lacks three basic capabilities:

a. The existing maintenance approach does not effectively identify the source or cause of diagnostic problems.

b. When diagnostic problems are identified, the maintenance and support approach does not effectively report the diagnostic problems.

c. When problems are reported, the Services lack individuals or organizations assigned the primary responsibility to analyze and fix the cause of the diagnostic inaccuracy.

4.1.2 Continuous Feedback of Relevant Technical Information Lacking

The diagnostic and design improvement processes lack continuous feedback of relevant technical information. In the absence of such feedback, many problems remain invisible. In order

for DoD to address a diagnostic inaccuracy problem, a systems feedback and analysis approach is needed that reports the problem source, identifies corrective actions, and provides justification to expend corrective action resources.

DoD MDC systems do a reasonable job of tracking reliability, maintainability, and availability. However, they are ineffective at identifying diagnostic inaccuracy problems. The available MDC information is abstracted to such a high level that the data lack relevant technical information necessary to determine if the reported factors are at desirable levels or they simply represent the original immature diagnostic performance delivered with the design.

4.1.3 Organizations Accountable for Diagnostic Improvement Lacking

The responsibility and authority for identifying diagnostic inaccuracies, developing diagnostic improvements, and implementing corrective actions reside at different organizations for each of the diagnostic elements. Each of these organizations has other responsibilities that focus on immediate problem solutions. Diagnostic inaccuracy problems, if identified, tend to be ignored since funding is usually directed at solving immediate problems, such as buying spares, sending an item to a depot, etc. However, the necessary resources to fix diagnostic element problems must come from another funding source that is more difficult to access.

4.1.4 Data Not Used for Diagnostics

The large amounts of maintenance-related data available within the Services are rarely used to support diagnostic and system design improvement. These DoD MDC systems have been justified based on requirements to collect maintenance-related data in support of non-diagnostic specific areas. In general, these systems meet or exceed the information objectives for their intended areas of support: logistics planning, availability tracking, reliability tracking and maintenance production management.

The individuals who receive this information are rarely in functional organizations that focus on diagnostic element improvements; and when they are, they find that the information lacks specific data fields necessary to permit correlation across product and maintenance levels.

4.1.5 Poor Data Entry Interfaces

The point-of-data entry interfaces for DoD MDC systems are inefficient, promote inaccuracies, duplicate efforts, and are non-responsive to the maintainers' needs. In general the DoD

MDC systems are automating the old paper-based MDC concept and lack the transparent data collection capabilities found in the commercial case studies.The lack of portable point-of-data entry interfaces, that may be taken to the maintenance site, are impacting work load, exacerbating data accuracy problems, and inhibiting transparent data collection capabilities.

4.2 THE FULL POTENTIAL OF MDC SYSTEMS ARE NOT BEING REALIZED

The DoD MDC systems as well as supporting automated data processing (ADP) capabilities carry over many of the same problems as the manual systems they are replacing. Many of the normal benefits of automation are not being fully realized because of the continued need for manpower-intensive input and the limitations of the hardware and software hosting the MDC systems.

4.2.1 DoD Systems Not Targeted Towards Diagnostic Capabilities

DoD MDC systems are focused on keeping the maintenance logistics pipeline filled by automating the old paper-based maintenance history tracking and reporting processes. The Services use this information for logistics planning and reporting maintenance production. As individual DoD MDC systems have evolved, the benefits to the maintenance community have extended into areas such as scheduling, parts life tracking, personnel and training tracking, etc. However, the MDC-related maintenance workload is labor intensive, and the technician actually performing the maintenance rarely receives any direct benefit in the diagnostic process.

4.2.2 DoD MDC Systems Do Not Support the Maintenance Process

Even when available MDC information could be used to support on-equipment maintenance, it is rarely used due to the time it takes to get this information out to the maintainer. In contrast, many of the commercial MDC systems use portable maintenance aids (PMAs) to provide near real time diagnostic support at the maintenance action site. These PMAs provided technical information, maintenance history, and diagnostic procedures.

The lack of immediately available maintenance history and diagnostic source information at the DoD maintenance site creates situations where the technicians are prone to remove the wrong item(s) for more diagnosis at an intermediate shop area, or to remove multiple items knowing that one or more of the items are still serviceable (adding to the no-defect-found rates).

4.2.3 DoD MDC Systems Do Not Effectively Identify and Codify Reported Problem Data

In general, the data stored in the DoD MDC data bases lack the necessary information to trace a specific maintenance action from its initial diagnosis through to resolution. Without this information, correlation of needed corrective actions becomes extremely difficult and often impractical.

4.3 MDC PROCESS IMPROVEMENTS NEEDED

Resource burdens created by diagnostic inaccuracy are in direct conflict with budget reductions and the down-sizing of DoD support postures. Commercial systems have demonstrated an ability to overcome and avoid these inaccuracy problems by employing effective MDC capabilities. Many of these commercial MDC processes and technologies are available within the Services; however, the way the information is collected and used by the Services differs significantly.

We conclude that near term diagnostics improvement payoffs are achievable by feeding back existing diagnostic-related MDC information to an individual or organization that has the responsibility for improving diagnostic accuracy. However, improvement to diagnostic capabilities will require more than just changes in the mechanics or scope of MDC systems; rather, fundamental changes in maintenance capability and process management will be needed. Systems approaches for resolving inaccuracies will be needed and we conclude that DoD MDC related processes will require the following basic improvements.

a. Upgrade MDC hardware and software to increase the quality and applicability of data collected, and to increase MDC systems availability.

b. Improve weapon system specific front end (point of entry) data capture to increase data accuracy and completeness, to reduce operator work load, to accelerate the update and implementation of corrective actions, and to supplement the technicians' knowledge with training and current maintenance information.

c. Adopt new analyses capabilities to be used by accountable organizations at both the local and central levels that integrate information involving system configurations, maintenance actions, maintenance procedures, and identified discrepancies.

5. RECOMMENDATIONS

Diagnostic improvement and design maturation are continuing processes that require feedback of information, focused analyses of problems or inhibiting factors, and feed-forward of corrective actions. At present within DoD these processes have stagnated and are perpetuating the status quo. We have identified a number of appropriate MDC-related actions that should be taken to re-energize and accelerate these processes.

5.1 ESTABLISH A JOINT SERVICE DIAGNOSTICS IMPROVEMENT TASK FORCE

DoD should establish a Joint Service Task Force assigned both near and long term objectives to improve complex weapon system diagnostic capabilities. A near term policy and long term strategy for improving weapon system diagnostic accuracy are needed.

5.1.1 Near Term Accountability Approach

The task force should develop a near term approach for assigning improvement accountability to individuals presently working within each existing weapon system maintenance and engineering organization. The approach should insure that these people are assigned the appropriate maintenance data analyses and diagnostic element improvement responsibilities. It should make full use of existing MDC capabilities and insure that these individuals are given full and timely access to existing on- and off-equipment diagnostic parametric data as well as all DR information.

5.1.2 Long Term Road Map

The Task Force should be asked to develop a long term road map for implementing a diagnostics improvement plan. The approach we suggest for DoD is outlined in our previous *Joint DoD/Industry Study on Opportunities in Integrated Diagnostics* [Brown 1990] and recommends that DoD develop a planing framework to facilitate the implementation of integrated diagnostic

concepts. This planning framework should specifically address actions necessary to accelerate weapon system specific point-of-entry data capture for increasing data accuracy and completeness, to extend common MDC and ATE systems for collecting and disseminating applicable diagnostic-related information, and to establish requirements and incentives for acquiring and continuously improving "designed-in" MDC capabilities. In conjunction with this effort, the Task Force should assess the relative benefits, cost, and schedules for implementing the elements of the improvement plan. While this examination is on-going, we would further suggest that the Services not start any further enhancements to MDC systems without reviewing the synergistic opportunities of more efficient integrated process approaches in the commercial cases.

5.2 ACCELERATE WEAPON SYSTEM SPECIFIC APPLICATIONS

DoD, in conjunction with the above plan, should ask the Services to accelerate the demonstration and field use of available technology solutions for diagnostic improvement. Opportunities to apply existing diagnostic improvement technologies should focus on point-of-entry maintenance aiding, transparent data collection, centralized diagnostic performance analyses, and serial tracking and maintenance history recording of reparable items. DoD also should provide system contractors with the latitude to propose new MDC capabilities or add-ons to existing Service systems with the objective of increasing diagnostic capability. Specific near term opportunities identified during this research include the following:

a. Apply commercial-off-the-shelf (COTS) technology to support transparent data collection capabilities (i.e., bar-coding, portable memory/logic microcircuit devices).

b. Initiate quick reaction research efforts to demonstrate the feasibility and benefits of integrating reporting mechanisms across product and support levels (e.g. investigate the benefits of integrating the F-18 parametric ECAMS data with NALCOMIS and Aviation-3M information).

c. Accelerate implementation of the F-15 pilot debriefing aid (CFR) system and investigate opportunities to apply the concept to other weapon system operator debriefing manuals.

d. Investigate opportunities to automate manuals, fault trees, and maintenance processes on new and existing ATE (i.e., down-sized I-level ATE).

5.3 ENHANCE COMMON MAINTENANCE AND SUPORT SYSTEMS

DoD should direct the Services to improve the responsiveness and performance of existing common maintenance and support systems. Specific opportunities to add necessary diagnostic improvement functionality identified during this research include the following:

e. Improve up-time and responsiveness of common MDC systems to diagnostic user needs (i.e., reduce the excessive down time, improve the user friendly characteristics, and enhance the screen responsiveness of CAMS).

f. Conduct baseline analyses on available turbine engine data to expand prognostic capabilities (i.e., extend the full prognostic capabilities of CEMS IV and ECAMS to other engine types).

g. Link MDC information sources (i.e., adopt design changes that will allow CASS to electronically communicate with NALCOMIS).

h. Add functionality to support distribution, codification, storage, and analyses of data used and collected on front end information sources and ATE (i.e., increase codified SAMS maintenance data by interfacing directly with existing and proposed ATE, and automate CASS diagnostic accuracy analyses and feedback between I- and O-level maintenance).

5.4 DEVELOP DIAGNOSTIC TECHNOLOGY

DoD should establish R&D program elements to support technology development for diagnostic improvement processes that collect, store, analyze, and distribute MDC related information. Specific technology needs identified during this research include the following:

a. Integrated maintenance process tools to support and manage the integration of MDC information.

b. Electronic technical information presentation capabilities including interface and protocol standards, and display devices.

c. Configuration tracking and reporting tools that correlate maintenance procedures, testing procedures, parameter ranges, and diagnostic processes across product and maintenance levels.

d. Transparent data capture, remote data recording and collection, and distribution technologies from electronic BIT, mechanical fault indicators, and on- and off-equipment ATE.

e. Diagnostic analyses tools to support and manage both local and central diagnostic improvement needs.

APPENDIX A - DISCUSSION OF TERMS

A.1 SYSTEM DIAGNOSTICS

System diagnostics as used within the context of this paper is the practice of analyzing the cause and nature of a fault condition, situation, or problem and, based on this analysis, recommending an appropriate course of action.

a. Conditions relate to the current status of a system or its components. Examples of conditions include mechanical, chemical, or dielectric changes that occur due to exposure or use (e.g. wear, power loss, fatigue).

b. Situations relate to the operation and performance of a system under varying stress environments. Examples of situations are intermittent failures or electrical power fluctuations caused by external stimuli.

c. Problems relate to anything from a "hard failure," or an out-of-specification parameter, to a costly maintenance action. Examples of problems include electrical shorts, improper electrical gain, and false removal of a subsystem that retests OK at the next maintenance level.

The diagnostic analyses must identify the problem that needs to be resolved, quantify the impact resulting from the problem (both in terms of operational performance as well as the resulting maintenance and support burden), and identify remedial actions.

A.2 INTEGRATED DIAGNOSTICS

The Automatic Test Committee and Logistics Management Committee of the National Security Industrial Association (NSIA) defines the term "integrated diagnostics" as

> a structured process which maximizes the effectiveness of diagnostics by integrating pertinent elements such as testability, automatic and manual testing, training, maintenance aiding, and technical information as a means for providing a cost-effective capability to detect and unambiguously isolate all faults known or expected to occur in weapon systems and equipment in order to satisfy weapon system mission requirements [Brown 1990, p.80].

However, participants in recent joint DoD and industry workshops on "Opportunities in Integrated Diagnostics" have noted that the term is used in several different contexts and often with different meanings: to describe a design process relating to the integration of various diagnostic elements, describe an approach for acquiring various diagnostic elements as a package, and

describe isolated deliverable systems that provide the capability of integrating the benefits of various diagnostic elements [Brown 1990].

Consistent with the NSIA definition as well as the observations from the referenced workshops is the notion that diagnostics effectiveness is enhanced by the synergistic application of multiple diagnostic elements. Therefore, the term "integrated diagnostics" is used in this paper to represent the process of improving diagnostic effectiveness and maintenance efficiency through the integration of diagnostic elements that promote the process of diagnostic feedback, analyses, procedural improvements, design evolution, validation, and implementation.

A.3 MAINTENANCE EFFICIENCY

System performance effectiveness is a combination of the basic system capabilities, the proficiency of operators, the availability and sustainability of the system, the relative cost to operate, the maintainability, the resources (trained people, equipment, and facilities) needed to maintain, and the support cost burden. These factors are neither static over the system life cycle, nor are they independent of one another. A framework for integrating diagnostic elements must have the ability to address the influence that each of these factors will have on current system performance effectiveness.

Modeling techniques necessary to fully analyze the interrelationships among all of these factors do not exist, and they may be too expensive ever to develop. However, it is possible to address a major aspect of this performance: "maintenance efficiency" relative to maintenance and support costs. Although the total cost for optimum maintenance efficiency is not known, we may assume that the more efficient the maintenance and support process (at a specified level of availability and for a given tempo of operations), the lower the relative maintenance and support costs. Therefore, for a given level of availability (generally determined by specific mission needs), maintenance efficiency increases as the cost of maintenance and support decreases. However, the level of availability and the maintenance/support costs are not independent variables. They are influenced by many of the same conditions, for example, the proficiency of the maintenance personnel.

A.4 AVAILABLE REMEDIAL MAINTENANCE ACTIONS

Diagnostic analyses must consider available actions that can be accomplished at different levels within the operational and system support environments. For example, actions may be performed at a range of location: the system's operational position, any of a series of intermediate

maintenance facilities, or a central maintenance depot. Specific remedial actions are selected from a range of maintenance actions that consider the available resources at designated locations, the expertise of available personnel, the urgency to remedy the problem, and the relative cost to accomplish any action. Generally, recommended remedial actions will take on one or more of the following forms.

a. Maintenance Actions to Resolve Hardware Problems: These actions may include removing and replacing components (at a subsystem or component level), adjusting settings, restoring of integrity (tightening, connecting, soldering, etc.), and cleaning.

b. Maintenance Actions to Resolve Software Problems: These actions may include working around hardware deficiencies through software patches, correction of software defects, improving code efficiency, and retargeting or improving applications.

c. Maintenance Actions to Revise Procedures: These actions may include revising technical manuals, modifying embedded procedures within test or support equipment, modifying maintenance concepts, and improving training practices.

d. Subsystem or Component Redesign: These actions may occur at various maintenance, support and design levels depending on the extent of the design modification. These actions are generally justified based on the results of operations and maintenance information feedback.

A.5 MAINTENANCE DATA COLLECTION

MDC is the process of collecting maintenance related information, and sending this information to a repository for subsequent analyses or management planning. With computer technology advances, many of the manual MDC processes are being automated. Figure A-1 highlights common architecture surrounding a generalized MDC system. Although the specific elements as well as the modes of communication will vary from application to application, this diagram is intended to establish a common frame of reference for MDC discussions.

The following, identified during Integrated Diagnostics Workshop [Brown 1990], are key MDC application attributes that influence commercial diagnostics and maintenance efficiency improvements.

a. Reduced human error and maintainer workload by transparently collecting and processing information (i.e., direct input from a data transfer unit or direct input from automatic test equipment).

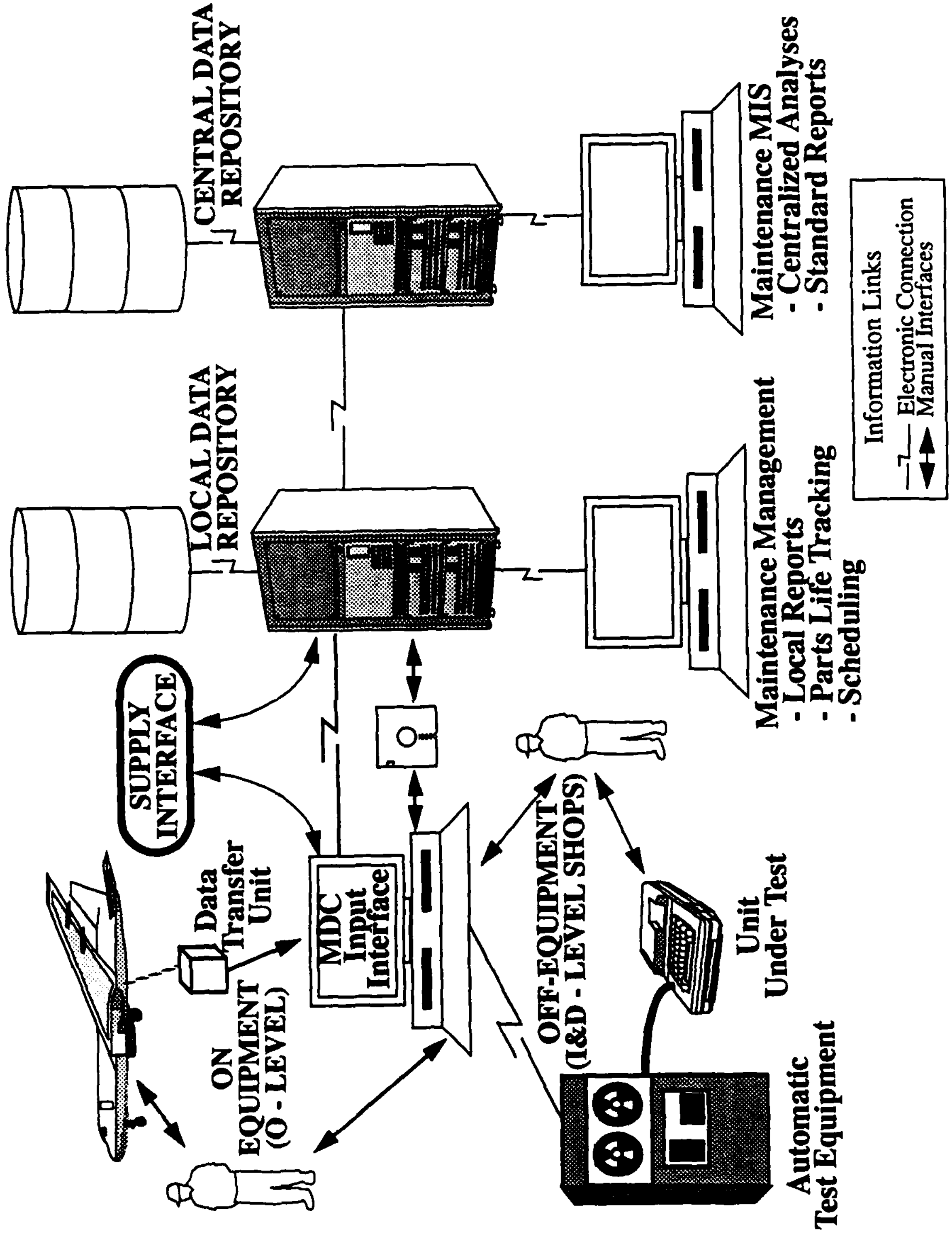

Figure A-1. Maintenance Data Collection Architecture Links.

b. Collected and stored system performance and operational status for future analysis.

c. Applied user-friendly input techniques at the maintenance interface where the data input could not be automated.

d. Automated local analysis of current and historical system information to help identify and localize maintenance problems (i.e., using information in the local data repository).

e. Applied implementation approaches that focused on closed loop maintenance data feedback capability through a centralized organization.

f. Provided rapid central analyses capabilities that were responsive enough to influence on-going production, and improve current and future maintenance effectiveness.

g. Automated configuration management of products, support tools, and maintenance technical manuals

A.6 DIAGNOSTICS AND MAINTENANCE EFFICIENCY IMPROVEMENTS

Systems design approaches for diagnostic and maintenance improvement are needed which feed back observed problems, develop hypotheses as to their cause, test the hypotheses, develop and test proposed solutions, and implement corrective actions.

Improvements to diagnostics and maintenance efficiency are directly dependent upon effective maintenance data collection and feedback to a responsible agent who has the authority to correct a deficiency. The following illustrates the direct dependence that diagnostics and maintenance efficiency have on the collection and analyses of maintenance data.

a. If maintenance performance data are not collected, trends will be difficult to compute.

b. If low diagnostic performance trends are not noted, problems will not be identified.

c. If a diagnostic problem has been identified, but not to the responsible authority, it will probably not be fixed.

d. If the benefits of resolving a diagnostic problem can not be quantified, responsible authority will not be given needed resources.

e. If the solution does not get to the responsible implementor, the benefits will not be realized.

APPENDIX B - SUMMARY OF SYSTEMS AND PROGRAMS EVALUATED

The following sections provide an overview of the systems and programs evaluated during this study. Figure B-1 summarizes the characteristic repair and servicing information used by the Services. At present, MDC systems used by the three Services are based on the collection and storage of this repair and servicing information. This information is then sent to various centralized data repositories for subsequent use and analyses.

B.1 AIR FORCE

The Air Force is in the process of developing and implementing several integrated MDC and maintenance-related information systems. Figure B-2 illustrates the communication interfaces between these major systems.

B.1.1 CAMS

The Core Automated Maintenance System (CAMS) is intended to automate and standardize the Air Force base-level maintenance data collection. Each CAMS is local to a maintenance organization (or base) and sends the collected information to a central repository. CAMS is accomplishing this by automating many of the maintenance information reporting forms and by permitting the maintenance technician to enter information directly into the system. Previously these forms were filled out by the maintenance technician and then later keypunched into various maintenance data collection systems (the specific collection systems depended on location and Air Force command).

The specific type and range of collected data is also being standardized across Air Force maintenance facilities, and many of the maintenance data collection systems (Maintenance Data Collection (MDC) system, Maintenance Management Information Collection System (MMICS), F-16 aircraft Centralized Data System (CDS), and B-1B Configuration Status Accounting System (CSAS), etc.) are being consolidated into CAMS.

CAMS is increasing the relative speed of data collection while improving the accuracy and accessibility of the information collected. As such, it is improving the management and utilization of existing maintenance resources by enhancing and standardizing the flow and availability of automatic data processing (ADP) logistics information.

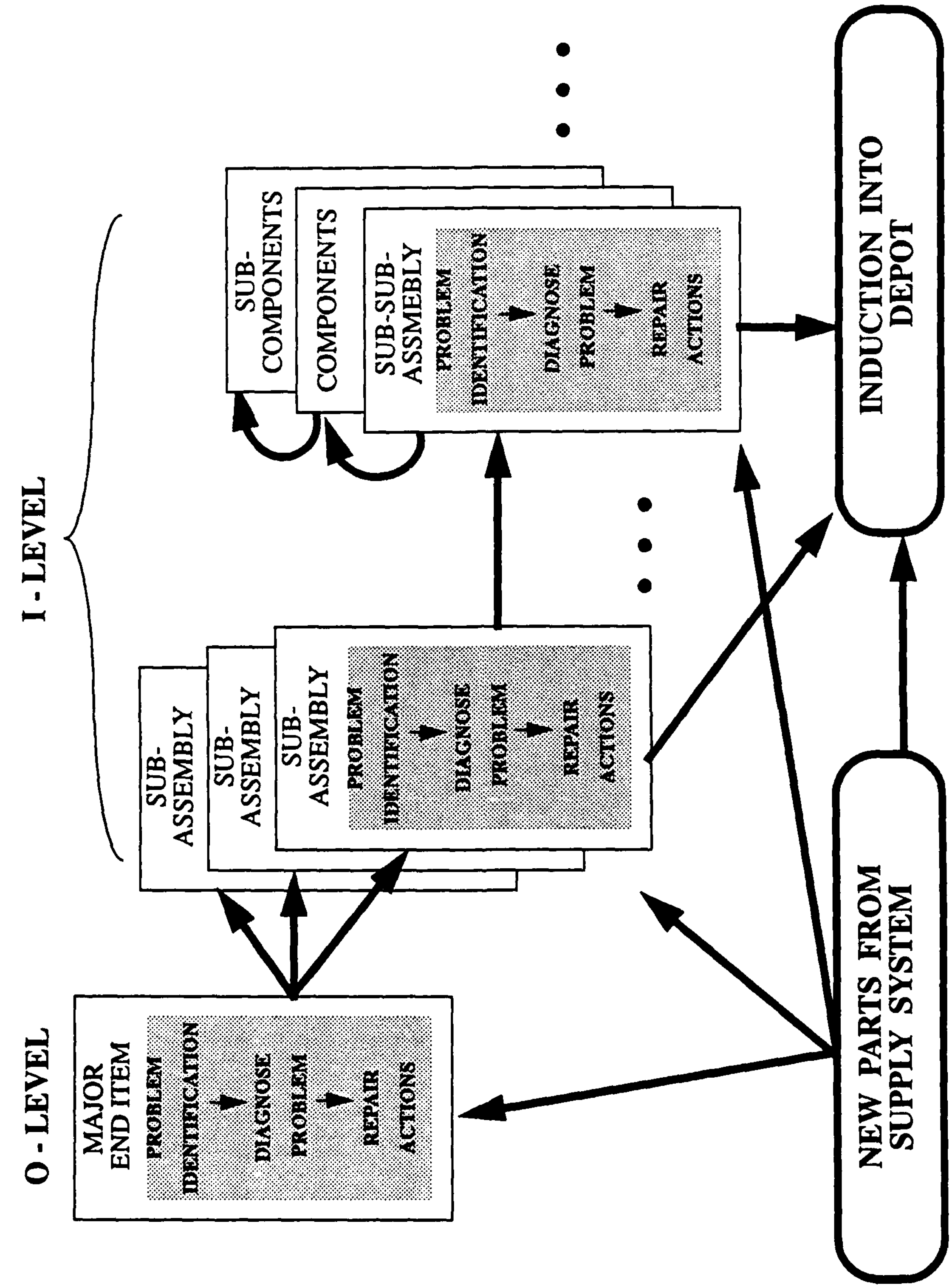

Figure B-1. Maintenance Information Flow Based on Parts Decomposition (for Repair) Across Levels of Maintenance.

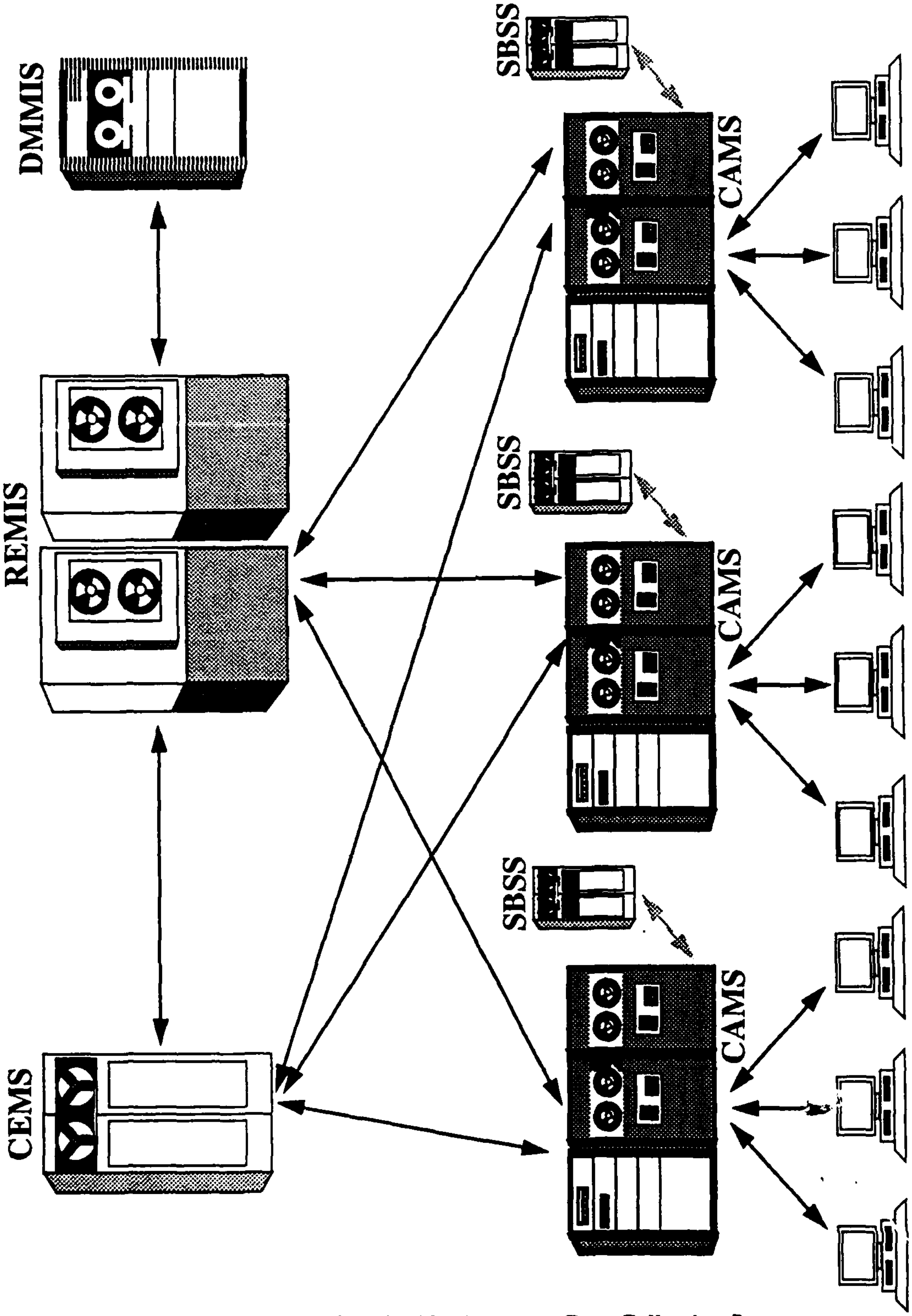

Figure B-2. Air Force Standard Maintenance Data Collection Systems.

The first Data Project Directive for CAMS was issued in May 1983. Subsequent to that time CAMS has become the standard base-level maintenance system for aircraft, engines, trainers/ simulators, support and test equipment, some munitions, and communications-electronic systems.CAMS can hold approximately six months of data-on-line and up to another two years of data on tape. It is hosted on the standard base level computer, and as of December 1989, is installed at 84 locations. By the end of FY91 the CAMS Program Office at the Standard Systems Center, Gunter AFB, AL, plans to have a total of 113 systems supporting 111 main/host bases and 153 guard/reserves sites.

The CAMS program has evolved through a series of planned phases. One of the next planned changes to CAMS will be the interface (shown on a dotted line on figure B-2) to the Standard Base Supply System (SBSS).

Current maintenance data collection element formats are based on Work Unit Codes (WUC). The data elements for the WUC system include a number of standardized codes such as the WUC itself, the Action Taken Code, How Malfunction Code, When Discovered Code, and Type Maintenance Code. Many of the maintenance actions reported into CAMS require the serial number and the part number of the item undergoing some maintenance action and the next higher level of assembly thereby designating where the item is installed. Other information that is collected and stored in CAMS includes discrepancies noted by operations. Built-In-Tests (BIT) fault codes, and input from pilot debriefing sessions. This information is used to generate a maintenance work orders. From this information evolves requirements for other information in the form of plans and schedules, workload tracking, quality control/quality assurance, spare part requirements and tracking, item/system status tracking, and management tracking and progress reporting data.

The data collected by CAMS is used for maintenance production, control, and planning at the base level. In addition most of this data is forwarded to Headquarters Air Force Logistics Command to be entered into the logistics information systems used to support the logistics processes of maintenance manpower and supply requirements definition, acquisition, distribution, and maintenance.

The data collected by CAMS is incident to the maintenance and system diagnostic processes, and not intended to specifically support system diagnostic capabilities. A detailed description of the data collected by CAMS and the specific sources of this data may be found in the Maintenance Data Collection User's Manual (Air Force Manual 66-279, Volumes 1-26). In addition, the justification and rationale behind the need for specific data may be found in the Air Force Technical Order-0020 (series).

B.1.2 CEMS

Comprehensive Engine Management System (CEMS) is an on-line database developed to provide management and tracking of aircraft turbine engines and related equipment. It was developed by the Air Force Logistics Command to satisfy management requirements including configuration management, serialized tracking, Time Compliance Technical Order (TCTO) tracking, and maintenance data collection. Several conditions lead to the development of CEMS: (1) an Air Force Inspector General report on engine management in December 1973 indicated that the data systems were not responsive to the current needs and that these needs would increase with the new F-15 and A-10 aircraft engines, and (2) in the mid 1970s the Secretary of Defense directed the Air Force to implement a concept termed Reliability Centered Maintenance (RCM) that requires work to be accomplished based on need rather than predefined times or cycles.

CEMS was systematically approached in increments. Increments I, II, and III are completed. CEMS IV is in place; however, the full implementation for new engines and bases is evolving. Increments I and II divided the implementation of critical-parts tracking for different engine types. Increment III implemented the status reporting, inventory control, pipeline analyses, accounting, distribution, and requirements computation for all engines.

CEMS currently tracks approximately 70,000 units (engines, module, APUs etc.) for location, status, configuration, TCTO management, and installation. In addition, there are a number of engine components and accessories (critical safety of flight and time change items) that have life limits determined by engine flight hours or thermal cycles. The CEMS program office, located at Headquarters, Air Force Logistics Command, Wright Patterson AFB, indicated that approximately 1.4 million serialized parts are tracked and this number equates to less than 1 percent of all the serialized items on engines. AFM 400-1 addresses what is to be tracked by CEMS.

The data capture for this parts life tracking (PLT) covers the full range of options: manual recording of flight hours by the pilot, manual reporting of flight hour information by the maintenance technician based on meter readings, and direct electronic down-load of flight hour readings through a portable maintenance aid. The maintenance action information is sent to CAMS (or MMICS) and the rest of the data is sent and stored at the CEMS central data base at Tinker AFB.

CEMS IV is intended to support engine diagnostics and trending analyses. It accomplishes this task by integrating the engine performance data and maintenance data. The most complete implementation of CEMS IV is for the TF-34 engine on the A-10 aircraft. The Turbine Engine Monitoring System (TEMS) records parametric engine performance data and down-loads to CEMS. This information coupled with the oil analysis program (OAP), component life expenditures, and other maintenance data already collected by CEMS. This combined information is used to develop a condition profile for the engine. This profile may then be used as an indicator of actions required on that engine.

At present, only the T-34 engine technical data has been analyzed sufficiently to yield the full range of prognostic and diagnostic opportunities. Efforts to analyze and organize the technical data for other engines that posses this parametric monitoring capability are continuing. At present, the engine maintenance technicians are not able to use this diagnostics capability to its fullest extent since they are not always certain what the trend data they are collecting actually indicates.

B.1.3 REMIS

Reliability and Maintainability Information System (REMIS) will be an on-line centralized database for status and inventory reporting, configuration accounting, and reliability and maintainability performance data. The program was started in 1983 and was established as a Headquarters Air Force directed program. The purpose of REMIS is to put in place a standard Air Force system to collect essential data to support reliability and maintainability at all levels of the Air Force. Its goal is to increase readiness and sustainability of USAF weapon systems by improving availability, accuracy and flow of essential equipment maintenance information. REMIS will provide real-time access to Air Force equipment and maintenance information for analyses of trends, excessive maintenance costs, and quality problems.

When completed, REMIS will provide an on-line distributed data base for weapon system product, maintenance, configuration, utilization, and status data. The availability of the data will permit automated analyses and immediate access to "user defined" reports for studies and analyses. REMIS will consist of four subsystems: (1) Equipment Inventory, Multiple Status & Reporting Subsystem (EIMSURS), (2) Product Performance Subsystem (PPS), (3) Generic Configuration Status Accounting Subsystem (GCSAS), and (4) MICAP (Mission Capable Awaiting Parts) and Awaiting Parts Subsystem (MAPS).

EIMSURS will provide inventory control, status reporting, and equipment utilization by serial number. Most of the items tracked by this subsystem are major inventory end-items. The specific items to be tracked are identified in AFR 65-110, and REMIS will provide real-time feed back relative to "assigned to" information.The status reporting will identify system problems (multiple problems if they exist, not just the top problem). The utilization by serial number will, among other things, help support the budget development. The initial operating capability (IOC) of EIMSURS occurred in December 1989.

PPS will collect and store information from various Air Force maintenance data collection systems. The objective is to have on-line one year's record of on-& off- equipment maintenance data as well as summarized data for the past five years. Off-line it will have the capability of retrieving all transactions for the life of the specific inventory item, plus five years. Specific

information the PPP will store include (1) Full maintenance data history, (2) Maintenance deficiency reports and service reports, and (3) Actual performance information as well as Logistics Support Analysis Record (LSAR) and Time-Compliance Technical Order (TCTO) predictions. This information may be used for problem item identification, unit to unit performance comparison, and warranty performance monitoring. The IOC of PPS is projected for September 1990.

GSCAS will provide configuration status accounting from the component, to the Shop Replaceable Unit (SRU), to the Line Replaceable Unit (LRU), to the system level. It will also include the configuration program identification number (CPIN) for the required software. GCSAS will track both hardware and software configuration items and identify what is authorized and what is actually installed. GSCAS also will provide for the management and tracking of TCTO's. The specific contractual delivery date for GCSAS has not been established yet; however, the program office at Wright Patterson AFB, OH anticipates IOC of this subsystem during the summer of 1992.

MAPS will tie together the status of the systems being tracked, the configuration of needed parts, and the process of tracking needed parts. It will identify and isolate MICAP items, provide analyses of MICAP items, and provide status/tracking information for needed parts. Funding for the development of this subsystem was in the FY91 President's budget. If funded, it will take approximately 26 months to develop.

B.1.4 DMMIS

Depot Maintenance Management Information System (DMMIS) is a resource management and planning system being developed for depots. DMMIS is intended to replace twenty-nine existing management systems, and to collect and control depot maintenance planning, management, and production control information. The host computer is Tandem and the program is applying commercial off-the-shelf software packages through a series of steps.

The first step includes the development of a data base to support the bill-of-materials, routing, and workorders. This portion is currently in operational and acceptance testing. The second step includes the development of an interface to supply and will provide subsystems to support material control. This portion of the DMMIS system is currently being coded and initial delivery for testing is anticipated late spring 1990. Step 3 will incorporate the planning portions of Manufacturing Resources Planning (MRP II). Anticipated completion is late summer 1990. Step 4 will include the shop-floor and cost management capabilities. This portion is anticipated around the end of the year.

DMMIS will first be installed and tested at Ogden Air Logistics Center, Hill AFB UT to support depot maintenance of the Technical Repair Center (TRC) for landing gear. The DMMIS system will then be further refined to support other TRCs and installed at other Air Logistics Centers within the Air Force. The next projected refinement will support the engine depot TRC.

In order to fully understand the function and purpose of DMMIS, it was necessary to understand the generic process for item repair within a TRC depot environment. The landing gear depot repair processes were used as examples.

A repairable end-item is received at the depot. It may be (1) a full subsystem that is tracked as a field replaceable end-item, (2) a sub-component that is tracked as replaceable end-item in a field environment, or (3) individual parts that are removed and replaced in the field and are tracked as end-items. If the end-item is an assembly, it will go through the necessary disassembly operations in preparation for the detailed inspection, refurbishment, or repair as required. Various inspections are required at each stage both before and after process work. The results from this flow are (1) condemned parts and requests to supply for new replacement resources and (2) good parts that may be put back into a holding inventory.

If the end-item is not an assembly, it will go through the appropriate inspection and repair as required. The results from this flow are similar.

Most serialized end-items lose their identity and traceability after the incoming inspection. There are exceptions for some components (such as some safety of flight items, selected engine components, etc.), and in these rare cases, the items are tracked by their serial number even within the depot. *These are exceptions*, generally only **quantities** of specific end-items that are introduced in the depot repair process are tracked. As replacement needs for condemnations or consumable spare parts are identified, new parts are requisitioned from the supply system.

If an end-item is serialized controlled in the field, the new serial number is not assigned until the end-item status is achieved (note the multiple states that an end-item may have as discussed above: end-item assembly, sub-component, etc.). There is an extremely low probability that the original parts of a specific assembly will be aggregated and recombined in the refurbished end-item.

DMMIS is intend to help plan and support the coordination (negotiations for work to be accomplished) between the item managers and the depot. The depot facilities need to account for capacity (facilities and people), spare part needs, through-put, material control, etc. DMMIS will provide the data base to track quantities of the respective end-items against historical work load, maintenance action averages, and available capacity. It will also permit the depot to maintain maintenance inventory records, compute material requirements, and schedule shop-floor activities. The maintenance action data collected will be stored in REMIS.

B.1.5 CFR

Computerized Fault Reporting CFR is a prototype concept that was initially developed and managed by personnel at the Air Force Logistics Management Center (LMC) at Gunter AFB, AL The prototype CFR is a computer program shell that will run on the Air Force standard personal computer. The CFR was not illustrated on Figure B-2.

The initial thrust for this concept began back in 1983 when Tactical Air Command (TAC) noticed that the pilots and maintenance personnel were not using the trouble-shooting technical order for the F-15 aircraft. These trouble shooting technical orders, referred to as debriefing books, were intended to take advantage of the BIT, cockpit fault and caution lights, and pilot noted problems. Using this information these debriefing books would systematically carry the pilot and maintenance technician through a comprehensive fault tree to the specific source of a problem.

TAC discovered that these debriefing books fell into disfavor for several reasons:

(1) The books were too complicated and took too long to follow through to the end.

(2) The fault tree was based on early information and many of the fault codes were incorrect (i.e., immature).

(3) There was inadequate feedback as to fault tree problems and when discovered there was no easy method to correct (on average it takes up to 270 days to update the T.O.)

As a part of this study, McDonnell Douglas computerized (automated) the fault tree structure. It is interesting to note that this process alone, identified and forced the contractor to fix approximately 350 logic errors and diagnostic voids in the fault tree. The CFR was hosted on the Air Force standard computer (Z-248), and effectively becomes a front end processor to CAMS. Based on the available BIT, fault logging information, and the pilots input, the CFR progresses through an automated fault tree. Once completed, that data is entered directly into CAMS and the necessary work orders are generated to fix the identified problem.

The prototype CFR demonstrated more accurate fault assessment, decreased debriefing time, and faster turnaround of aircraft forms. As a result of the study and demonstration, the F-15 SPO has decided to complete development of the CFR and field this diagnostic support tool with the F-15E aircraft.

The LMC personnel expressed one concern regarding the CFR. Based on early analysis/ projections they expect that the identified discrepancies noted during the debriefing to increase by a factor of 2 to 4 initially. They projected that this will be due to the improved diagnostics and the presence of previously hard to locate problems. However, once fully mature, and the relatively

high level of previously unidentified discrepancies have been corrected, LMC personnel believe that overall maintenance performance and efficiency will improve significantly.

Finally, they noted that there were still opportunities to further enhance this concept by integrating approaches that would permit the direct down loading of BIT and fault logging data into a data transfer unit. This would eliminate the potential of error (remove the "air-gap") while decreasing the maintenance technician's workload.

B.1.6 RAM & TMRS

The Air Force has the Technical Order Reliability Asset Monitoring (RAM) program for tactical missile systems. The program is managed out of Warner-Robins Air Logistics Center (WRALC). The guiding documentation (and operating instructions) are found in Technical Order 21M-1-101 (3 January 90, Change 2). This Technical Order implements the Tactical Missile Reporting System (TMRS) that is in place at the various field locations. The TMRS consists primarily of a computer program that operates on a personal computer in the missile maintenance shop. The required reliability information (including the identified fault codes from the respective test sets) against each serial numbered item are entered in a data base. The data base is sent on a monthly basis via floppy disk to WRALC.

The current TMRS system originated as a result of the combined efforts of HQ TAC and the LMC at Gunter AFB. The individual that has been responsible for the management and control of the program up until recently has been stationed at HQ TAC. However, this individual will be transferring (along with the responsibility to continue the TMRS management) to WRALC. This is intended as an interim approach until a new system called the Combat Ammunition Supply System (CASS) is developed and fielded. Concepts being looked at for CASS include, bar coding of part number (P/N)and serial number (S/N) data, and on-line reporting.

Due to the basic design of most of the missile systems, very little detailed repair of end-items (major missile components) is performed in the field environments (the classical I- & O-levels of maintenance). The current operational concept is moving towards a "Wooden-Round" approach where the field maintenance is generally limited to inspections, high level functional testing (either BIT or with a test set), aircraft loading, and remove and replacement of major end-items (if applicable). Beyond these responsibilities, the missile maintenance technician handles the missile as though it were a wooden-round. As a result of this maintenance concept, coupled with the fact that many of the components are serialized ontrolled and tracked over their life cycle (due to reasons associated with explosives or parts classification), the information recorded in the field under the TMRS is directly traceable to the depot repair actions. The current RAM program

currently tracks the observed field problem (BIT code, test set fault code, inspection discrepancy, etc.) for each returned item and compares this data with the actual depot repair actions.

B.2 NAVY

B.2.1 NAMP (A-3M and NALCOMIS)

The overall Navy (Air) maintenance data collection effort is covered by the Naval Aviation Maintenance Program (NAMP), OPNAVINST 4790.2E, dated 1 January 1989. The process is paper intensive and maintenance action reporting is done on 5-part (carbon) forms called Visual Information Display System/Maintenance Action Form (VIDS/MAF). These forms track the specific maintenance action by a job control number, (JCN), the system identification (tail number, serial number, etc.), type of problem, malfunction code, action taken, etc. If parts are removed and sent to another area or organization for inspection, testing or repair additionalVIDS/ MAF are generated. The flow and process involving these forms is illustrated in Figures B-3 and B-4. VIDS/MAF forms are also sent to a Data Service Center (or equivalent) for key punch entry of the data. At shore facilities this is often accomplished by a support contractor. On an aircraft carrier, this function is generally performed by personnel on board the ship. The data (referred to as aviation 3M data) captured in this process is sent via tape to the Naval Maintenance Support Office (NMSO) in Mechanicsburg PA. NMSO sends reports and summary data to program managers and to Air Systems Command as well as the Naval Aviation Logistics Data Analysis (NALDA) System. Summary reports of compiled VIDS/MAF data are also sent from the individual Data Services Facilities (or equivalent facilities) to the respective I, O, or D level maintenance organization that submitted the forms.

At NALDA the data is further processed and selected portions are put on line for fleet-wide use. Typical users include Fleet Commanders, depot, Type Commanders (TYCOMs) and the Systems Command.

The Naval Aviation Logistics Command Management Information System (NALCOMIS) supports the NAMP and automates the maintenance data collection (3M data) discussed above. It is being implemented as a computerized (aviation maintenance management) information system that will facilitate direct data entry, auto information validation, and timely update and retrieval of essential data. The initial phase of the NALCOMIS program is being implemented at I-level and is focusing on the supply system interface.

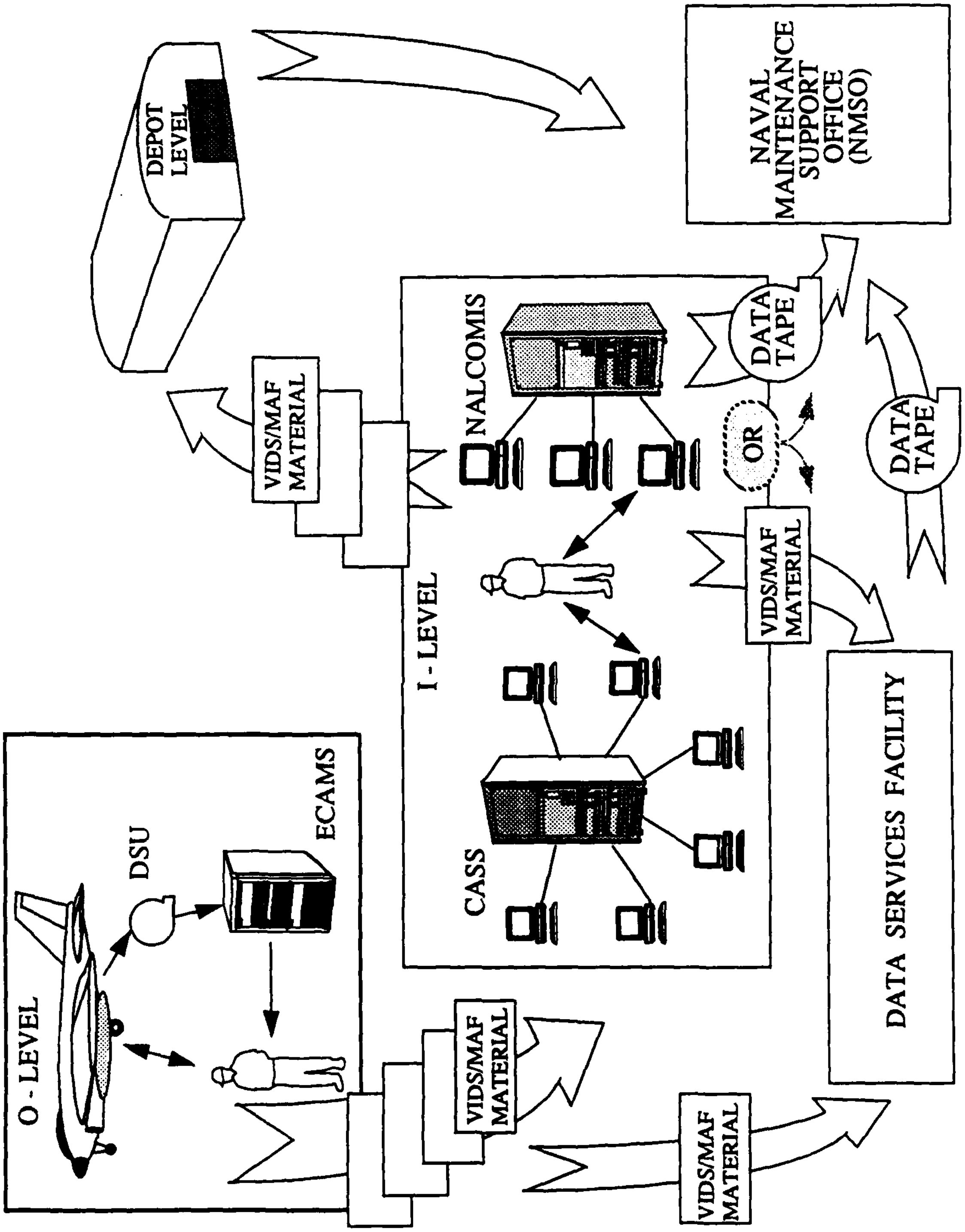

Figure B-3. Navy MDC Process Flow.

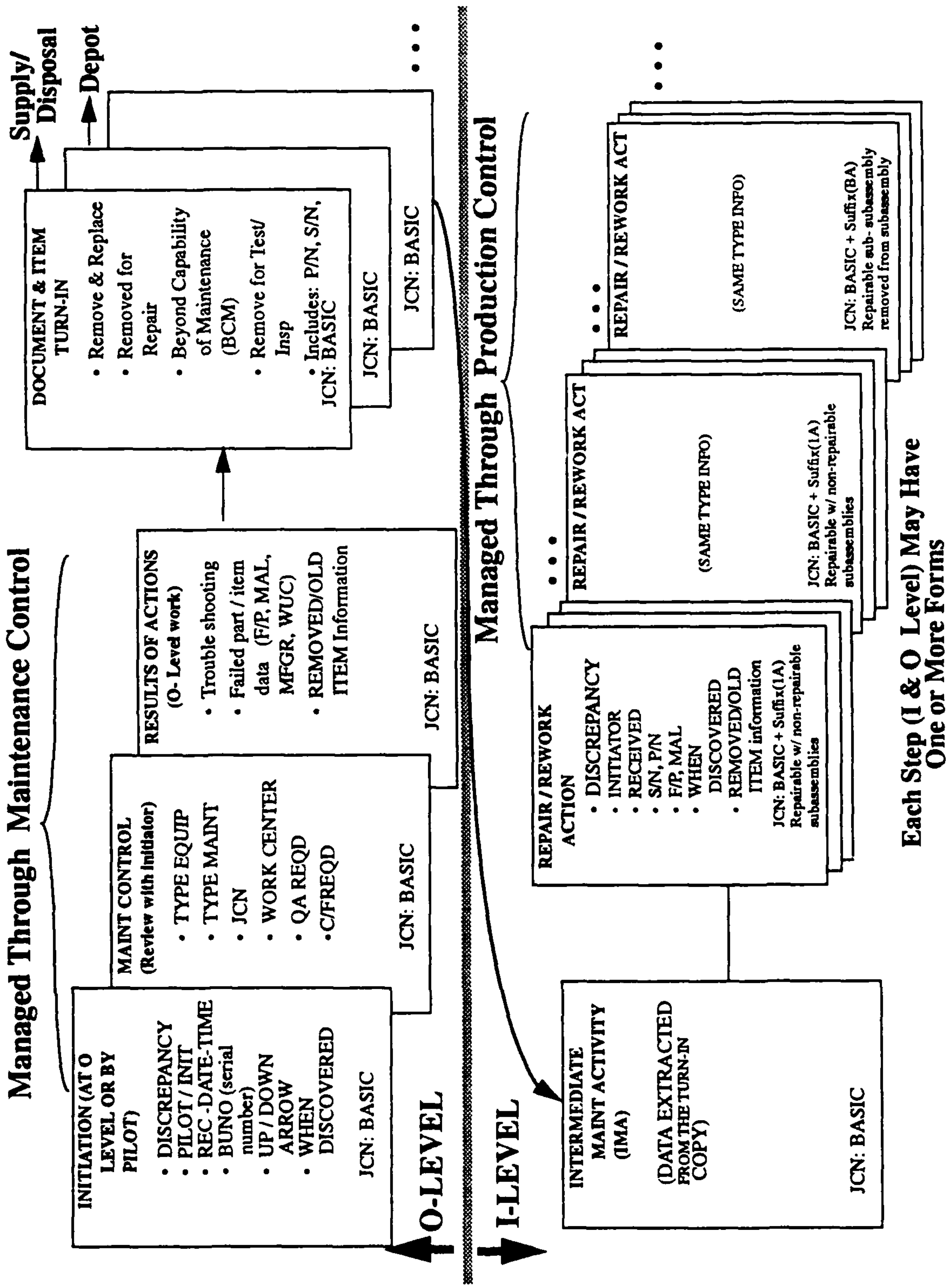

Figure B-4. Processing of Navy VIDS/MAF Forms.

B.2.2 ECAMS

The Enhanced Comprehensive Asset Monitoring System (ECAMS) is an engine and aircraft asset tracking and management system. ECAMS includes a capability to down-load aircraft and engine in-flight parametric data through a data storage unit (DSU) on the aircraft. The information is then used by the technician for parts life tracking engine, prognostics, etc.

At present the Navy has several aircraft that can down-load engine and aircraft in-flight data. Table B-1 lists these aircraft and asset reporting/monitoring systems. The unshaded areas represent deployed operational capability.

Table B-1. Enhanced Comprehensive Asset Monitoring System (ECAMS) and Other Engine Monitoring System

A/C	Down Load Medium	System
A - 7	Tape Cartridge	Engine Monitoring System Ground Station (EMSGS)
F/A - 18	TTM / DSU *	ECAMS (with Martin Marietta software)
F - 14	DSU	ECAMS (with GE software)
E -2C	Tape Cartridge	EMSGS
AV - 8B	DSU	Map, Operator, Maintenance Station (MOMS)
V -22	DSU	VMARS
A - 12	DSU	(TBD)

* Early models of the F/A-18 have a tape transport magazine (TTM) later models have the (DSU).

The EMSGS and its onboard monitoring capability in the A-7 is reported to have saved at least 22 aircraft. Although, there is no way of conclusively verifying this benefit, it was projected based on the most probable result had the pilot or maintenance technician not received the critical information captured by the EMSGS system. This system is used primarily at the O-level and captures engine event data. Based on the data, the technician will direct specific actions (i.e., Require an inspection based on an over temperature or over speed condition). The information, as presently applied to the engine in the A-7 aircraft, is not used for parts life tracking and this data is not stored or retained.

The application and use of ECAMS on the F-18 is split between the I- and O- levels. The information collected by the DSU (and TTM on the earlier aircraft models) is extensive and may be loosely grouped into 4 categories: (1) mission data, (2) engine data, (3) strain gauge data, and (4) avionics data. All of the shore based F-18 ECAMS are networked together, and as such, the F-18 aircraft has the only centralized engine parts life tracking (PLT) capability in the Navy. The DSU is generally removed from the aircraft when it is 80% full and is not used for each post-flight analysis. In an operational scenario, the DSU is removed more frequently; however, it goes to the operations organizations first to extract the mission data. Therefore, the information is seldom available for immediate maintenance diagnostics applications. A summary of the type of F-18 ECAMS information that fall in categories 2, 3 and 4 is provided in table B-2.

The strain gauge data along with data concerning the number of landings and amount of flight time are collected via the ECAMS and put on a Navy form called the "Yellowsheet" or Flight Readiness Evaluation Data Sheets (FREDS). This information is sent to the Naval Air Development Center to monitor and compute the fatigue life extension (FLE) on the individual aircraft. At present some individuals question the integrity of the strain gauge data. One suggested source of error originates from the fact that the strain gauges are not considered prime mission equipment (PME), and as such, the aircraft is authorized to be flown without strain gauges connected.

Table B-2. Summary of F/A-18 ECAMS Data Types

1. Strain Data: High and low stress values for the strain sensors on board aircraft.
2. Life Use Index (LUI) Data: The LUI values are accrued during flight for the engines installed in the aircraft.
3. Pre-Event Data: Data shows engine parameters 1, 5 & 10 seconds preceding a detected engine event.
4. Avionics Data: Shows the BIT for Avionics equipment on board the aircraft:
   a. DMS: Digital Map Set
   b. RMDI & LMDI: Right & Left Multipurpose Display Indicators
   c. NFLR: Navigation FLR
   d. SDC: Signal Data Computer
   e. DSU: Data Storage Unit
   f. HF Comm: High Frequency Communication
   g. ASPJ: Airborne Self-protection Jammer
   h. CWS: Countermeasures Warning System
   i. ADC: Air Data Computer
   j. MMD: Master Monitor Display
   k. MFD: Multifunction Display
   l. CSC: Communication System Control
   m. INS: Inertial Navigation Set
   n. SMS: Stores Management System
   o. FLR: Forward Looking Radar
   p. RDR: Radar Set
   q. LST: Laser Spot Tracker
   r. FCA & FCB: Flight Control Computers A & B
   s. HARM: High Speed Anti-Radiation Missile
   t. MSDRS: Maintenance Signal Data Recording Set
   u. D/L: Data Link
   v. Comm 1 & Comm 2: Communications Radios 1 & 2

23. Tactical Air-To-Air & Air-To-Ground Data: Aircraft and weapon parameters for launches
24. FIR Data: In-flight aircraft parameters recorded 1/second.
25. Post-Event Engine Data: Shows engine parameters 1 & 10 seconds following an event.
26. Hard Landing Data: Vertical and normal accelerations, and weight for current and hardest landings.
27. SDC Fuel Data: Fuel system data if fuel system event is detected.
28. AOA/Q Matrix: Time spent at various angles of attack and dynamic pressures.
29. Engine Exceedingly Reports: Pre- and post- engine event data for troubleshooting.

The engine data is used primarily for PLT. The data is automatically collected and sent to a central data base. The software as currently implemented for the F-18 aircraft engines (GE: F-404) does not support diagnostics nor trending analyses. In addition to the PLT, the information is currently used by the managers to select engines with lower time for extended cruses, to identify appropriate modules/asset for swapping and change-out based on operating time, and to flag critical event data that might drive a maintenance action.

All of the avionics BIT flags and flight parameters that are being recorded by the DSU are archived with the ECAMS. However, the use of this data for analyses has been minimal to date. The primary exceptions are for (1) post mishap analyses, (2) an engine mission profile study by GE, and (3) a recent study into strain gauge creep.

The ECAMS capability for the F-14 engines (A+ and D upgrades with the new GE: F-110 engines) has only been available for about 6 months. It currently supports both I- and O- level; however, the I- level is not on line. The engine PLT information is forwarded to GE for management and tracking. The GE software for the ECAMS supports Trend and Event Diagnostics System (TEDS) on the F-110 engine. The F-14 depot has requested a data link to the central data base.

The EMSGS capability on the E-2C is very similar to the A-7. It has been in place only for about 6 months (since the black box was added to the T-56/427 engine).

The systems for the AV-8B and the V-22 will be storing the information in a database that will provide user sort capabilities. The MOMS system (on the AV-8B) is designed around a man-portable (80386 microprocessor based) field system that will support three separate functions: map station, operator station, and maintenance station. The software loaded on the hard drive and the selection of peripheral devices will determine the specific station function.

The A-12 is projected to have two DSU like devices to support the ECAMS functions. The reported intent is to separate the mission data from the maintenance data.

At present the Navy is attempting to pursue a program to standardize the ECAMS software for the F-18 and F-14 aircraft. They are focusing on the GE software with the TEDS capability. In addition, they are also investigating options to field a standard personal computer compatible software version to supplement the approximate 110 ECAMS computers (PDP11) now deployed.

B.2.3 AWAR

The Navy has in place an Airborne Weapon Analyses and Reporting (AWAR) system for tracking and monitoring the reliability, maintainability, availability and quality of the deployed missile systems. The program is documented and controlled by the Naval Airborne Weapons

Maintenance Program (NAWMP), OPNAVINST 8600-2A, dated 1 Mar 89. It is currently used to monitor approximately twelve Navy missile systems.

At present, the maintenance technicians record the information on paper forms. The Fleet Tactical Analyses Center is investigating options to transition to a personal computer (PC) based data collection system that will permit using bar code readers. This is being tested at several weapon stations.

The type of information collected includes the following: date and time of maintenance, the operator, item nomenclature, P/N, S/N, source code (where it came from and why sent - "fleet unknown", captive carry, etc.), Lot No., test times, test results (including BIT, parametric performance information, etc.), present condition codes, disposition, technical directive applied, failure category codes, and test equipment used. This data is then tracked for the life of the missile, along with the configuration and repair and rework data from the depot. A significant number of components in most of the missiles are tracked by S/N or P/N and Lot No. Therefore, the AWARs data base has the capability of tracking all actions and major components of individual missiles over the life cycle. This data when coupled with actual live firing testing (with telemetric data) provides the Navy with a comprehensive data base for detailed analyses.

B.2.4 CASS

The Consolidated Automated Support System (CASS) will update and replace the Navy's current suite of automatic test equipment. CASS will be located at the I-level maintenance facility and will be used to detect and fault isolate date subsystem and circuit card problems and to verify that corrective maintenance actions have resolved problems. The program is currently in Tech Eval/Op Eval at Patuxent River, with the Low Rate Initial Production (LRIP) decision programmed for the August 1990 time frame. Option 1 of the contract will acquire 99 units with an approximate 16 month delivery time for the first units. The full rate production is projected for the 1992 time period and there are 3 years of contract options.

The CASS system will automate the VIDS/MAF form and the identified fault codes will be entered into the forms "Discrepancy" box automatically. The CASS system will incorporate a bar-code reader and the reader will be used to identify the part number and serial number of the following: the unit under test (UUT - box, circuit card, etc.), the interface device (ID) needed to connect the UUT to the CASS, any required cables, and the test program sets (TPS). The embedded software will check the compatibility of each selected item for the specific test and will record this information for future analyses if required. The CASS system is being sized to store approximately 6 months of collected maintenance data.

CASS will incorporate paperless technical manuals that are resident in the system. In addition, the CASS system is designed to fault detect and fault isolate itself. All of the CASS stations will be networked together, thereby creating one single data base of the stored maintenance information, configuration, documentation, and technical manual information. Preliminary indications are that, due to the embedded training and technical information capabilities, training time for both the technician and the CASS maintainer will be 1/2 to 1/3 that of the existing systems.

At present, the CASS design does not permit direct communication with the NALCOMIS system. The VIDS/MAF forms must be generated (automatically produce paper forms) by the CASS, and then the information must be keypunched into either the 3M or NALCOMIS data base. The program office noted that the direct electronic link was eliminated due to budget and program constraints; however, key interfaces that will permit easy modification have been retained in the system specification. Finally, since at a specific location the CASS stations are all networked together the program office does not believe that potential modifications to incorporate this automated communication between CASS and NALCOMIS will be significant.

B.2.5 IETM

The Navy is investigating opportunities to use Interactive Electronic Technical Manuals (IETM). David Taylor Research Center (DTRC) is the Navy representative to a tri-Service committee that is chartered to develop the requirements, standards, and specifications for an IETM type device that delivers interactive electronic presentation of technical manual information. These specifications are expected to include hardware, software and data standards that define the functional and content requirements needed to meet operational and maintenance requirements. Earlier tests were conducted under the Navy's NTIPS (Navy Technical Information Presentation System) program that preceded this current effort. In order to demonstrate the feasibility of the concept, the NTIPS program conducted a series of controlled field tests on sea- and air-systems using both experienced as well as inexperienced maintenance technicians. The following summarizes the results of these tests.

(1) Tests comparing the use of paper based technical manuals and electronic technical information presentations to maintenance technicians demonstrated increased maintenance accuracy that was directly attributable to the use of electronic presentations. The maintenance tasks involved the rudder-trim system of the F-14A aircraft. 100% of the test subjects (12 out of 12) successfully located the faults with the electronic presentation while only 43% (5 out of 12) were successful with

paper technical information. In addition, there were 35% fewer errors by the inexperienced technicians who used the electronically delivered technical information, "The electronic Delivery of Automated Technical Information For Logistics Support of Navy Weapon Systems: Potential, Systems: Potential, System Description, and Status", Feb 1989, [DTRC-89/007].

(2) Tests were conducted for the AN/SPA-25D shipboard radar repeater in a maintenance shop. Again 100% of the technicians correctly fault isolated the problem using the electronic presentation (11 experienced and 13 inexperienced technicians). However, only 58% of the technicians using the paper technical instructions (7 inexperienced and 7 experienced) were able to isolate the fault without help from the test monitors. The test also revealed that the trouble shooting time was twenty-four times faster with the electronic display than with paper. [DTRC-89/007]

B.3 ARMY

B.3.1 ULLS AND SAMS

The Unit Level Logistics System (ULLS) is a personal computer based system that is located at the unit maintenance (O-) level and is used to both manage and request support for actions that are beyond the capability of the unit level maintenance. ULLS successfully completed its milestone 3 (production decision) this year and is replacing the old "paper-forms" with floppy disks. When using the ULLS, paper is used only for backup, and ULLS communicates via the disks both to the next higher level of maintenance support (the Direct Support or General Support Units) and to the Standard Army Retail Supply System (SARSS). Information pertaining to the specific requests (status, inventory, priority, etc.) is sent both directions (to and from ULLS) via these disks.

The Standard Army Maintenance System (SAMS) is an automated maintenance management system that is hosted on the Tactical Army Combat Computer System (TACCS). SAMS milestone 3 was approved in FY 86 and the active duty Army implementation is essentially complete. It replaces several old maintenance management systems including the Maintenance Reporting and Management (MRM) System, and the Maintenance Activity Management System (MAMS). There are two different software implementations of SAMS. SAMS-1 is used at the direct support maintenance company found in the separate brigade, division, corps, and echelons above corps; and the general support maintenance company at echelons above corps. SAMS is used to improve the management of maintenance actions, work loads, and resources. SAMS

currently receives inputs via the disks originating from ULLS and has the capability to communicate with other systems using the standard phone lines and DDN communication links.

SAMS-2 is used at the forward support battalion, main support battalion, and material management center of the division and separate brigade. SAMS-2 is used at these various maintenance management levels to enhance program guidance. It accomplishes this by controlling and coordinating maintenance work load functions, monitoring mission capable rates, and coordinating repair parts utilization to maximize equipment availability.

Data in SAMS can be accessed instantly to fulfill management needs in controlling, coordinating, reporting, analyzing and reviewing maintenance actions. Information from SAMS-2 is also sent to the Army Material Readiness Support Activity (MRSA) The maintenance information flow and the maintenance action flow are illustrated on Figures B-5 and B-6.

Until the introduction of SAMS, the Army relied primarily on a series of individual study efforts to collect operational system performance and availability information. These efforts are grouped under a program titled "Sample Data Collection" (SDC). Each of these efforts is relatively short term, focuses on a single system, and results in a summary report. The SDC information collected is of little value for providing continuous maintenance feedback information to support diagnostic improvement.

By contrast, SAMS provides a continuous feedback capability and provides insight into the system and subsystem reliability and availability status. In addition, this new information is collected as a beneficial by-product of the SAMS maintenance management support function. However, the SAMS information will not presently support effective diagnostics analyses. The level of maintenance information detail is significantly less than the information details collected by either the Navy or Air Force MDC systems.

Although, useful feedback potential of SAMS diagnostic related information is significantly less than the MDC systems in the Navy and Air Force, SAMS demonstrates the potential of applying current technology to a functional need and developing a new process that is not based on a paper MDC concept. The demonstrated by-products of the SAMS approach are (1) a system that supports the users needs, (2) collects maintenance related data (that was only available with the SDC program) without increasing workload, and (3) provides the medium for collecting more detailed diagnostics related information in the future.

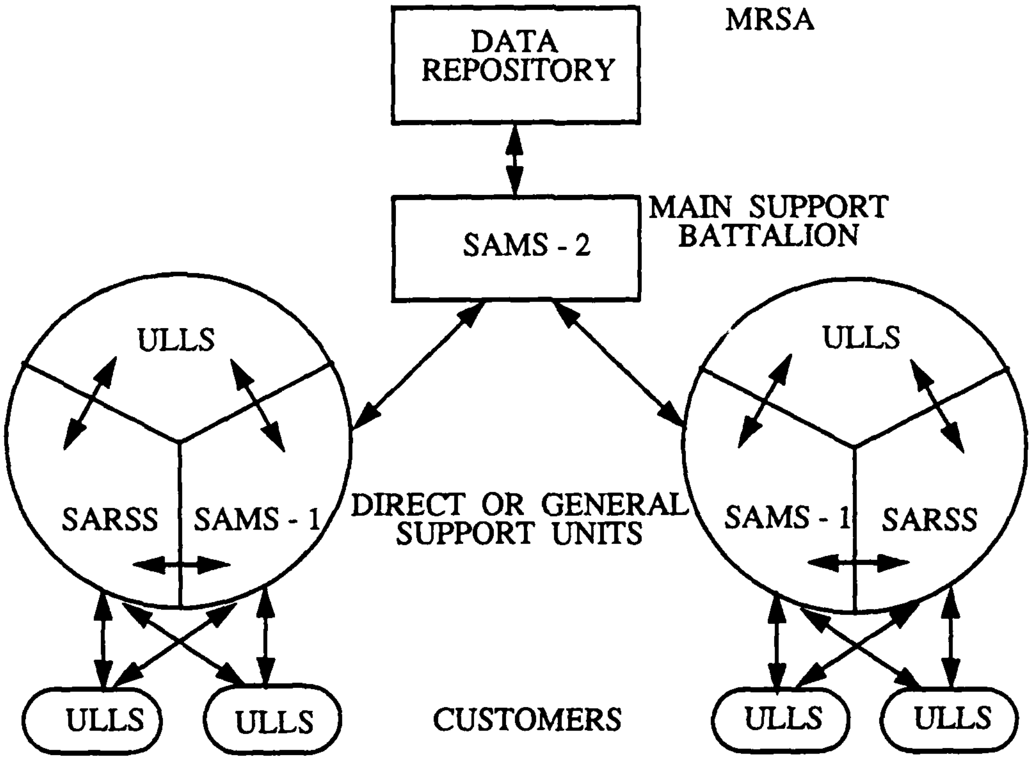

Figure B-5. Army Maintenance Information Interfaces.

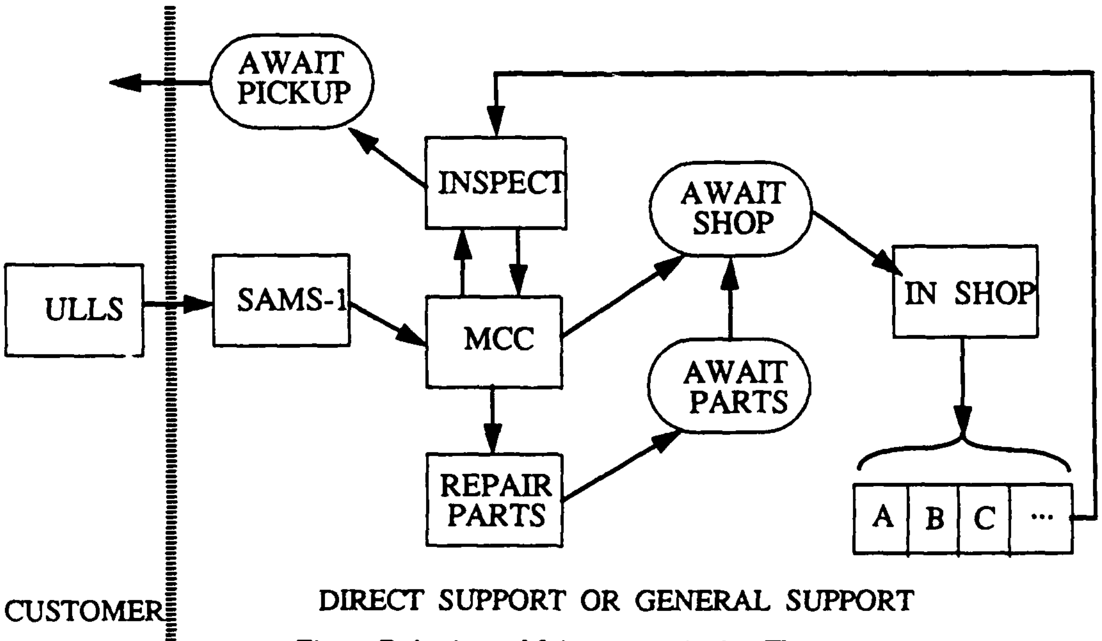

Figure B-6. Army Maintenance Action Flow.

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LIST OF ACRONYMS

ADP	-	Automatic Data Processing
AFB	-	Air Force Base
ATE	-	Automatic Test Equipment
AWAR	-	Airborne Weapon Analyses Reporting
BIT	-	Built-in-Test
CAMS	-	Core Automated Maintenance System
CASS	-	Consolidated Automated Support System
CDS	-	Centralized Data System
CEMS	-	Comprehensive Engine Management System
CFR	-	Computerized Fault Reporting
CND/RTOK	-	Can Not Duplicate / Retest OK
COTS	-	Commercial-Off-The-Shelf
CPIN	-	Configuration Program Identification Number
CSAS	-	Configuration Status Accounting System
D-Level	-	Depot Level
DDN	-	Defense Data Network
DMMIS	-	Depot Maintenance Management Information System
DoD	-	Department of Defense
DR	-	Deficiency Reporting
DSU	-	Data Storage Unit
DTRC	-	David Taylor Research Center
ECAMS	-	Engine Comprehensive Asset Monitoring System
EIMSURS	-	Equipment Inventory, Multiple Status & Reporting System
EMSGS	-	Engine Monitoring System Ground Station
FLE	-	Fatigue Life Extension
FOC	-	Full Operational Capability
FREDS	-	Flight Readiness Evaluation Data Sheets
FY	-	Fiscal Year
GCSAS	-	Generic Configuration Status Accounting System
HQ	-	Headquarters
I-Level	-	Intermediate Level
ID	-	Interface Device
IDA	-	Institute for Defense Analyses
IETM	-	Interactive Electronic Technical Manual

IMA	-	Intermediate Maintenance Facility
I&O	-	Intermediate & Organizational
IOC	-	Initial Operational Capability
JCN	-	Job Control Number
LMC	-	Logistics Management Center
LSAR	-	Logistics Support Analysis Record
LRIP	-	Low Rate Initial Production
LRU	-	Line Replaceable Unit
MAMS	-	Maintenance Activity Management System
MAPS	-	MICAP and Awaiting Parts Subsystem
MDC	-	Maintenance Data Collection
MICAP	-	Mission Capable Awaiting Parts
MMICS	-	Maintenance Management Information Collection System
MOMS	-	Map, Operator Maintenance Station
MRM	-	Maintenance Reporting and Management
MRP	-	Manufacturing Resource Planning
MRSA	-	Material Readiness Support Activity
NALCOMIS	-	Naval Aviation Logistics Command Management Information System
NALDA	-	Naval Aviation Logistics Data Analysis
NAMP	-	Naval Aviation Maintenance Program
NMSO	-	Naval Maintenance Support Office
NSIA	-	National Security Industry Association
O&M	-	Operations and Maintenance
O-Level	-	Organizational Level
OAP	-	Oil Analysis Program
OASD(P&L)	-	Office of the Assistant Secretary of Defense for Production and Logistics
PC	-	Personal Computer
P/N	-	Part Number
PLT	-	Parts Life Tracking
PME	-	Prime Mission Equipment
PPS	-	Product Performance System
R&M	-	Reliability and Maintainability
R,M & A	-	Reliability, Maintainability, and Availability
R&R	-	Remove and Repair
RAM	-	Reliability Asset Monitoring
RCP	-	Reliability Centered Maintenance

REMIS	-	Reliability and Maintainability Information System
S/N	-	Serial Number
SAMS	-	Standard Army Maintenance System
SARSS	-	Standard Army Retail Supply System
SBSS	-	Standard Base Supply System
SDC	-	Sample Data Collection
SRU	-	Shop Replaceable Unit
TAC	-	Tactical Air Command
TACCS	-	Tactical Army Combat Computer System
TAX	-	Tactical Air Command
TCTO	-	Time Compliance Technical Order
TEDS	-	Trend and Event Diagnostics system
TEMS	-	Turbine Engine Monitoring System
TMRS	-	Tactical Missile Reporting System
TO	-	Technical Orders
TPDR	-	Technical Publication Deficiency Reporting
TPS	-	Test Program Sets
TRC	-	Technical Repair Center
TTM	-	Tape Transport Magazine
TYCOM	-	Type Commanders
ULLS	-	Unit Level Logistics System
UUT	-	Unit Under Test
VIDS/MAF	-	Visual Information Display System/Maintenance Action Form
WRALC	-	Warner-Robins Air Logistics Center
WSIG	-	Weapon Support Improvement Group
WUC	-	Work Unit Code

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